

BIPV/BAPV Barriers to Adoption: Architects' Perspectives from Canada and the United States

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Ola Mousa

Abstract

Solar photovoltaic technology (PV) is a promising clean energy source that assists in climate change mitigation. This is due to solar PV having minimal greenhouse gas emissions when operating compared to burning fossil fuel. Solar PV is also a versatile technology owing to its multiple applications within the built environment.

Buildings are responsible for nearly half of the world's energy consumption; thus, reducing buildings' energy usage through environmentally-responsive design techniques, in addition to the application of PV products, can not only assist in reducing the energy consumed by buildings, but also contributes to mitigating the adverse effects of climate change. Architects, in particular, play a substantial role in achieving sustainable/environmentally responsive designs; hence, their collaboration is essential.

This study investigated American and Canadian architects' level of awareness and interest in Building Integrated Photovoltaic (BIPV) and Building Applied Photovoltaic (BAPV) products. It also aimed to shed light on the barriers that are responsible for slowing down the adoption process. This study was conducted in two phases: a) a web-based survey questionnaire administered to architects who have an active membership in the Royal Architectural Institute of Canada (RAIC), and the American Institute of Architects (AIA); b) in-depth interviews with architects and key informants in the solar industry.

The results indicated that architects are aware of PV benefits and the products available for buildings' application; however, they lack essential practical knowledge. Furthermore, the results indicated that PV systems' capital cost is the major perceived barrier to PV adoption in the

building industry. Other reported barriers are: the lack of government policies and financial incentives, the problematic grid connection process and the lengthy application lead times (barriers vary from one jurisdiction to another).

Recommendations based on this study's results include, but are not limited to, providing financial support mechanisms, simplifying the administrative procedures of financial support mechanisms and grid access permits, and offering education and training to architects through architectural associations and academic institutions.

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Dedication

“The mother's heart is the child's schoolroom”.

Henry Ward Beecher

This thesis is dedicated to my mother who never had the chance to go to university, and devoted her life to raise six kids. Mom, this is for you, for being a survivor, a caring and loving woman.

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1 INTRODUCTION

1.1 Background

For decades, global climate change, a phenomenon that results from human activities that increase the emissions of greenhouse gases (GHG), has been a pressing issue that has captured governments' and policymakers' attention. Multiple global efforts have been established to mitigate the adverse effects of climate change, with the United Nations Framework Convention on Climate Change (UNFCCC) or "Rio Convention" signed in 1992 being the most influential. Governments in many developed countries have adopted different policies and mechanisms to control the levels of GHG emissions that result from burning fossil fuels to operate buildings and industries. Accordingly, our built environment plays a significant role in climate change given that buildings consume substantial amounts of energy to operate, and this energy demand has been constantly increasing to accommodate growth in population and enhanced standards of living around the world.

Overall, buildings account for approximately 30 to 40 percent of the total energy consumed in developed countries (Ramesh, Prakash, & Shukla, 2010). For example, in the U.S. and Canada, buildings account for approximately 48 percent and 50 percent of the total energy consumed respectively (Architecture 2030, 2013b; Natural Resources Canada, 2013). Figure 1.1 illustrates the percentage of energy consumed by buildings in the U.S. compared to other sectors; whereas Figure 1.2 shows that 75 percent of the electricity generated in the U.S. is used to operate buildings (Architecture 2030, 2013a). Therefore, it is critical to address the design process and construction standards when attempting to achieve energy-efficient buildings.

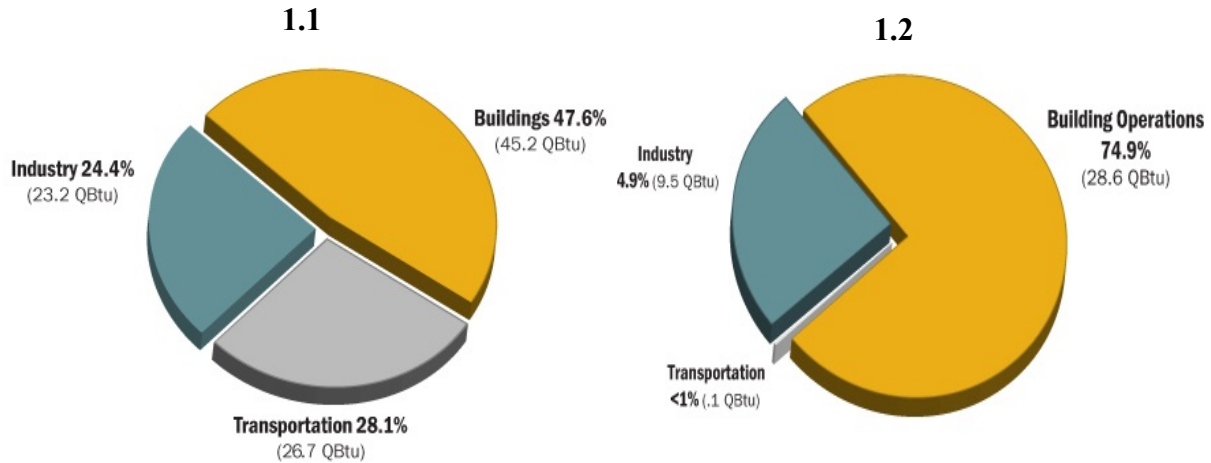


Figure 1.1: Energy Consumption by sector in the U.S. (quadrillion BTU)

Figure 1.2: Electricity Consumption by sector in the U.S. (quadrillion BTU)

Source: Architecture 2030, 2013b.

It is also important to emphasize that by undertaking an environmentally responsive design, such as the building form and proper site orientation, architects/designers could reduce up to 80 percent of the energy needed to operate buildings (Lechner, 2009). To achieve this, collaboration is required among different key stakeholders in the building industry. Despite developers, planners and engineers each playing major roles in shaping our built environment, architects in particular have the greatest influence on the design process from its inception to completion. Historically, architects have been known as creators. They are responsible for carrying out designs for diverse building types ranging from single family residential dwellings to a group of commercial and institutional buildings (The American Institute of Architects, 2013b).

Architects are trained to work with different building scales, envision their designs before they are built, and develop creative solutions to cater to different clients (AIA, 2013). Therefore, by collaborating with architectural practices, many opportunities can be seized to improve the

architectural quality of buildings along with their energy performance, therefore assisting in mitigating climate change (SHC-Task 41, 2009).

Architecture 2030, a North-American initiative that aims to raise awareness among architectural practices worldwide and urge them to annually reduce GHG emissions of the buildings they design, has been widely adopted in Canada and the U.S, as well as in other countries around the globe. The building sector, which includes architects, planners, engineers, builders and others, being a major GHG contributor, is required (by committing to the Architecture 2030 challenge) to achieve carbon-neutral buildings by 2030. Carbon-neutral buildings are buildings that do not depend on fossil fuel to satisfy their energy demand; they are designed by utilizing passive solutions to improve their energy efficiency and reduce demand.

In addition, by deploying on-site renewable energy sources, energy demands can be met without the necessity of consuming fossil fuel, or electricity generated offsite from fossil fuel, helping to mitigate climate change (Architecture 2030, 2013b).

Photovoltaics (PV) are a renewable energy technology that utilizes freely accessible solar radiation to generate electricity, and has minimal environmental impact during operation. The environmental impact for various products is usually evaluated by conducting a life cycle assessment (LCA), also known as “cradle to grave” assessment. In the case of PV, an evaluation of the production process of PV materials, module manufacturing as well as disposal processes is essential to determine any pollution prevention benefits, energy performance in addition to any cost savings gained from PV panels (Sherwani & Usmani, 2010; Stoppato, 2008; Keoleian & Lewis, 2003). For example, in a study that was published by NREL about PV life cycle assessment and the greenhouse gas emissions associated with it, the results show that when

comparing GHG emissions from various life cycle stages for PV and coal, the process of coal combustion emits the majority of GHG emissions, whereas in the case of PV, the majority of GHG emissions are emitted during upstream processes which include material extraction, production, module manufacturing and other processes, and PV modules have minimal GHG emissions during operation (National Renewable Energy Laboratory, 2012a).

Additionally, PV modules can seamlessly replace building components while also performing their original function of generating clean electricity. Building Integrated Photovoltaic (BIPV) and Building Applied Photovoltaic (BAPV) are ways to merge architectural designs with clean energy generation. BIPV and BAPV will be further discussed in Chapter 2, Section 2.6.2.

PV modules can be artistically integrated as roofs, windows, skylights, curtain walls and sunscreen devices. Attributable to their numerous potential benefits, and their compatibility with dense urban cores, there is a growing global demand for BIPV/BAPV products; therefore, public and private investments are currently focused towards developing products that meet the building codes and standards in addition to being reasonably priced (Frontini, Manfren, & Tagliabue, 2012).

1.2 Research Objective and Focus Statement

Historically, the market for integrating PV technology in architecture consisted of limited scattered niche applications; however, it has recently witnessed growth in many countries around the world such as Germany, Italy and France. Despite PV being a proven technology, Canada and the U.S. lag behind other industrial countries in terms of PV installations (Parker, 2008). It is worth mentioning that both countries have policies in place in different jurisdictions to promote the use of renewable energy technologies by providing renewable energy adopters with

various financial incentives (Ontario Power Authority, 2013; Palmer, Paul, Woerman, & Steinberg, 2011; California Energy Commission & California Public Utilities commission, 2007).

The literature indicates that financial incentives act as drivers that encourage the adoption of PV technology (Bertoldi, Rezessy, & Oikonomou, 2013). Additionally, Parker (2008, p.1945) claims that financial incentives are perceived by residents as preferred resources to overcome the high cost of PV modules.

For example, in California, the principal BIPV market in the United States (Lowder, 2012), the state government initiated “Go Solar California”, a state-wide initiative that targets the achievement of a Million Roof-Solar installations for the State of California. Go Solar California consists of two rebate programs that encourage the use of on-site solar applications: California Solar Initiatives (CSI) and New Solar Homes Partnership (NSHP). The initiative targets the installation of approximately 3000 MW of clean electricity on both residential and commercial buildings between 2007 and 2016 (CEC & CPUC, 2007).

In Canada, the province of Ontario is the leader in providing government financial incentives to renewable energy adopters. The Ontario Feed in Tariff (FIT), which is a renewable energy financial incentive program included in the Green Energy and Green Economy Act (2009), offers adopters the opportunity to sell their generated electricity to the utility grid at preferential rates (OPA, 2013). Ontario’s FIT came as a continuation to the province’s effort of encouraging the adoption of RE after initiating the Standard Offer Program (SOP) in 2006. The SOP offered financial premiums paid to small scale projects. Owing to its small revenues, the SOP program was unsuccessful in attracting a large number of adopters (Ontario Sustainable Energy Association, 2008).

This research explores the deployment of BIPV/BAPV products within the building sector in both Canada and the U.S.; it also investigates the potential drivers and barriers that might influence architects' decision-making in implementing a PV system within their projects. This research focuses specifically on architects for the following reasons. First, Architects are professionally trained to see the big picture in addition to their ability to design and supervise a wide range of residential, commercial and institutional projects, and to adhere to codes and standards. Real estate developers would have been considered if this study focused solely on the residential sector due to their contribution to the growth of the real estate market. Second, The architectural quality of buildings that are integrating PV technology is critical to achieving market penetration and PV technology acceptance by end users (SHC-Task 41, 2009). Therefore, and following the objectives of Task 41, a three year collaborative project among 14 countries carried out by the International Energy Agency (IEA) to address the integration of solar energy in architecture, architects' education and awareness are essential to achieve market penetration of PV technology (SHC-Task 41, 2009).

Methods of inquiry for this research include an online survey questionnaire, as the first phase of this research, directed to architects in Canada and the U.S. who have an active membership in The Royal Architectural Institute of Canada (RAIC) for Canadian candidates and The American Institute of Architects (AIA) for American candidates. Architects are selected regardless of their specialty or experience in deploying a BIPV/BAPV system. This method is used to gather a wide range of architects' perspectives and avoid biases in the sample. Phase two of this study is devoted to conducting semi-structured individual interviews of open ended question style with two categories of candidates: a) short-listed architects who indicated in the survey that they have already procured a BPV/BAPV system and indicated their willingness to further discuss their

experience; and b) key informants from various national solar industry associations and research and development organizations, such as The National Renewable Energy Laboratory (NREL), Canada Centre for Mineral and Energy Technology (CanMET), American Solar Energy Society (ASES) and Canadian Solar Industry Association (CanSIA). Interviews from category (a) are designed to identify the potential drivers /barriers that architects have faced during the process of deploying a PV system. Interviews from category (b) seek to capture higher levels of barriers facing the technology penetration from an expert point of view in addition to triangulate the information obtained from architects.

1.3 Research Questions

This study explores the following questions:

1. To what extent are Canadian and American architects aware of BIPV/BAPV technology benefits?
2. To what extent are they willing to consider the deployment of BIPV/BAPV products within their projects?
3. What are the major barriers that influence their decisions on whether or not to adopt a BIPV/BAPV system?

1.4 Expected Results and Significance

This study is expected to contribute to the existing literature by shedding light on two major issues: a) Canadian and American architects' level of awareness about BIPV/BAPV technology and their interest in deploying different BIPV/BAPV products within their new construction or retrofit projects; and b) the potential barriers responsible for altering their adoption decision. The data are collected and analyzed to draw a clearer picture of how architects, as major industry players, perceive PV technology and how willing they are to integrate it within their design process. As mentioned earlier, the quality of solar-architectural integration is vital to encourage

adoption by clients. In addition, any identified barrier to PV technology is to be examined and compared to barriers identified in the literature. Recommendations on how to overcome these barriers are provided utilizing best practices. This study is expected to add knowledge to different industry initiatives and programs concerned with improving the architectural design process, architects' awareness and education, with the goal of reducing the climate change impacts of buildings.

1.5 Thesis Structure

This thesis includes five Chapters.

Chapter 1 is an introduction to the subject outlining the reasons behind conducting BIPV/BAPV research. It also includes the research questions, significance of this study to the existing literature, as well as the expected results.

Chapter 2 is dedicated to providing a review of the existing literature concerning this study. The review of the literature addresses climate change and increasing global energy demands as issues to mitigate. It also suggests that BIPV/BAPV technology is one of many potential solutions, in conjunction with solar passive designs that can assist in mitigating climate change. Furthermore; any gaps in the literature are identified in this chapter.

Chapter 3 states, in detail, the methods utilized to conduct this research. It also offers a justification of why such methods are the best choice. This chapter further explores the study location, participants, and discusses the data collection and analysis procedure as well as any identified limitations.

Chapter 4 is dedicated to presentation of the research findings.

Chapter 5 discusses the findings and offers recommendations on how to overcome any identified barriers.

2 LITERATURE REVIEW

2.1 Introduction

This chapter provides a review of the literature concerning the role of photovoltaic technology in the built environment and to explore interconnected topics. The conceptual map shown in Figure 2.1 illustrates the relationship between PV technology application in buildings (such as BIPV/BAPV) and the process of achieving environmentally-responsive designs that not only plays a role in mitigating climate change, but also provides the opportunity to enhance the architectural quality and performance.

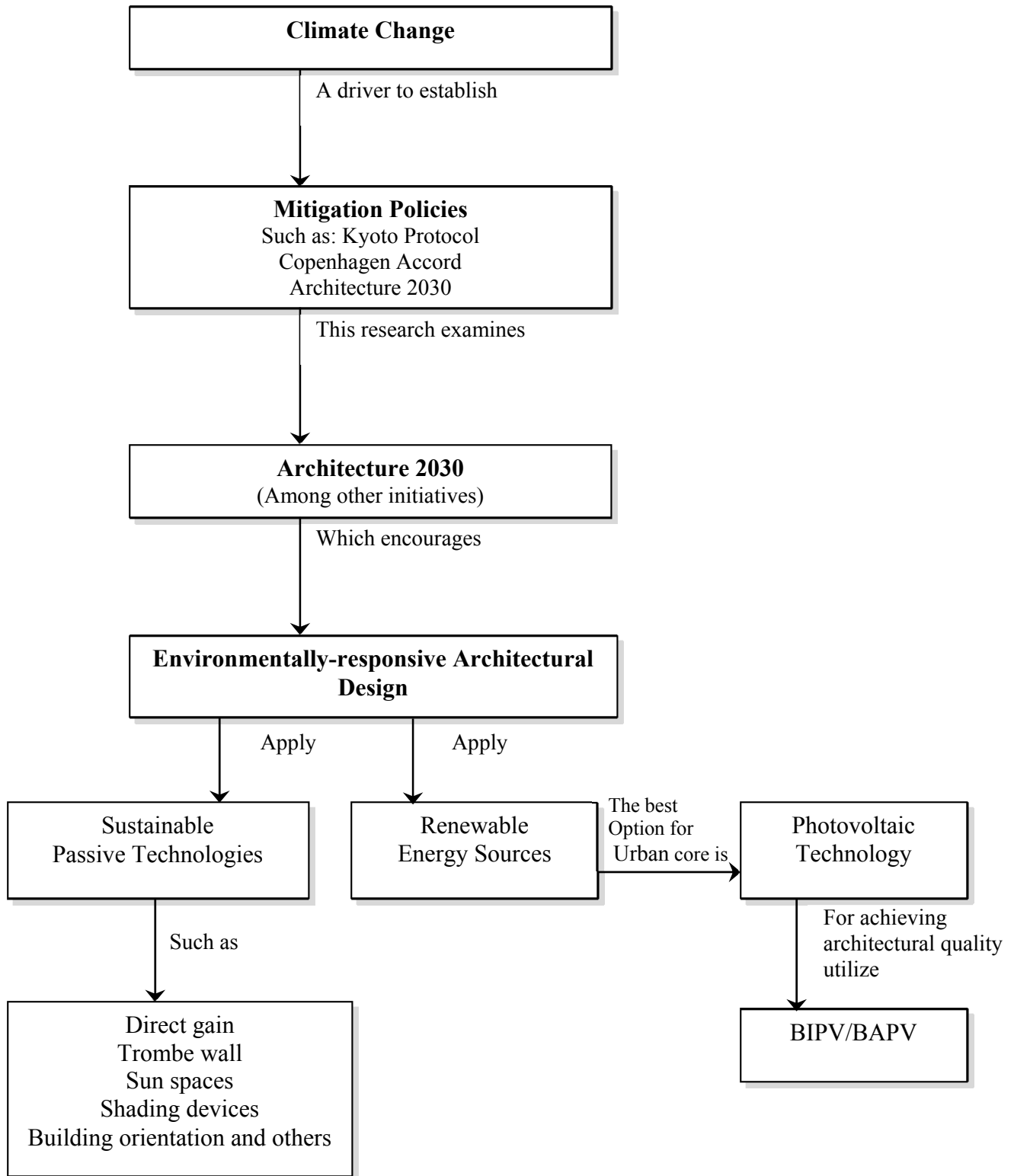


Figure 2.1: A conceptual diagram that illustrates the flow of literature topics

2.2 Climate Change Mitigation

The world's energy demand has been continually increasing owing to, for example, increased urbanization (half of the world's population lives in urban settings), transportation and the affordability of fossil fuels compared to other sources of energy (Dulal & Akbar, 2013).

According to Keleş & Bilgen (2012, p.5200) "The total primary energy demand in the world increased from 7223 Million tons of oil equivalent (Mtoe) in 1980 to 12,354 Mtoe in 2008". This increase in demand played a significant role in elevating the amount of greenhouse gas (GHG) emissions produced from consumption of fossil fuels (Haines, 2012). Additionally, Khatib (2011) suggests that the world's energy-associated CO₂ emissions are projected to surpass 35 giga-tons (Gt) by 2020 compared to 22 giga-tons in 1990.

Multiple observed changes are documented in the literature and are associated with high levels of CO₂ emissions. According to the fifth assessment report (AR5) of the intergovernmental Panel on Climate Change (IPCC) issued in 2013, "...the atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" (p.4). Studies claim that higher carbon dioxide (CO₂) concentration in the atmosphere is, the higher the atmospheric temperature and, consequently, greater negative effects on biodiversity, ecosystems and human health (Haines, Kovats, Campbell-Lendrum, & Corvalan, 2006; Intergovernmental Panel on Climate Change, 2013). Vector-borne diseases and allergies are some examples of health issues associated with Climate Change (Haines, Kovats, Campbell-Lendrum, & Corvalan, 2006).

Several international policies and regulations have been established to mitigate climate change and its negative impacts. The United Nation Framework Convention on Climate Change

(UNFCCC) is a global agreement that was adopted in 1992 and aims to stabilize ten greenhouse gases in the atmosphere (six are typically reported and they are: CO₂, CH₄, N₂O, HFCs, PFCs and SF₆) to a permitted level that does not disturb ecosystems. The UNFCCC has gained acceptance in numerous developed and developing countries (Golusin & Munitlak Ivanovic, 2011).

In addition, The Kyoto Protocol, a legally binding treaty to mitigate climate change linked to the UNFCCC 1997 agreement, was approved in December 1997 and brought into effect in 2005 with the enrollment of 141 countries (Krishnamurti & Hoque, 2011). The protocol operates by setting GHG emission reduction targets for each country that signs the treaty relative to its baseline levels measured in 1990 (Krishnamurti & Hoque, 2011). The Protocol set its first commitment period for the developed countries to achieve their emission reductions starting in 2008 and closing in 2012 (United Nations Framework Convention on Climate Change, 2008).

Due to the need for fundamental modifications in human activities and industries to meet reduction targets, several developed countries ignored their targets while other countries have actually withdrawn their commitment to the protocol. Among those countries withdrawing are Canada, the United States, and China, which has surpassed the U.S. as the world's largest greenhouse gas emitter (Diringer, 2011). Consequently, efforts are needed to extend the protocol commitment beyond its first commitment period (2008-2012). In 2009, the Copenhagen conference was held to extend the support for reduction mechanisms established by the Kyoto Protocol (Ghezloun, Saidane, Oucher, & Chergui, 2013). The Copenhagen conference succeeded in accomplishing some progress in recognizing that climate change is a pressing issue

particularly by the United States and other industrial countries such as China and India; however, it failed to establish a legally binding successor to the Kyoto Protocol (Ghezloun et al., 2013).

In December 2012, the Kyoto protocol was amended in Doha, Qatar to adopt a second commitment period (2013-2020) that binds industrial countries to decrease their GHG emissions by a minimum of 18% lower than 1990 levels. The Doha amendment also included an updated list of the "...greenhouse gases (GHG) to be reported on by Parties in the second commitment period" (UNFCCC, 2014, para 6).

However, mitigating strategies to reduce carbon emissions vary widely among industrial countries depending on their economy and the policies they establish to alleviate climate change. Yet, the success in reforming climate change depends largely on the effectiveness of these policies and the strategies they utilize to achieve carbon reduction targets. According to the Organization for Economic Co-operation and Development (OCED), governments must set clear policies such as, for example, putting a price on carbon emissions whether it is through applying taxes or trading emissions; and provide incentives for innovation in renewable energies and mitigation activities. Any established policy should also be accompanied with a detailed "communication strategy" to educate consumers about the benefits of carbon reduction (OECD, 2013; Virginie et al., 2011). As the OECD Secretary-General stated:

"...There is only one way forward: governments need to put together the optimal policy mix to eliminate emissions from fossil fuels in the second half of the century. Cherry-picking a few easy measures will not do the trick. There has to be progress on every front, notably with respect to carbon pricing, and that is what peer review and learning from best practice should help achieve." (Gurria, 2013, conclusion, para 2)

2.3 Architecture 2030

The mitigation policies mentioned above have captured the attention of a very influential segment of the world's economy, the building industry. Since buildings world-wide are responsible for nearly 45 percent of the energy consumption, and a comparable fraction of the world's greenhouse gas emissions (Butler, 2008), a greenhouse gas reduction initiative from the building sector would play a major role in mitigating climate change. One of the most recognized efforts globally is the Architecture 2030 challenge. Architecture 2030 is a non-profit organization that is based in Santa Fe, New Mexico. This U.S. based initiative was originated by architect Edward Mazria in 2002. The challenge targets the construction sector to reduce their greenhouse gas emissions over the next two decades. The 2030 challenge has been endorsed by the American Institute of Architects (AIA), the Royal Architectural Institute of Canada (RAIC), and over 400 professional organizations in approximately 54 countries around the world (Janda, 2011; Butler, 2008). As of 2012, Architecture 2030 has been accepted by nearly 52 percent of U.S. architectural practices (Architecture 2030, 2013b).

The Architecture 2030 Challenge claims that by 2030 over three quarters of the U.S. built environment will be either newly constructed or retrofitted. This represents a big opportunity for the building sector to start immediately working on improving building designs to meet the challenge. In reality, getting the building industry to modify their way of carrying out their designs is not an easy endeavor, particularly in developing countries. Architects usually cater to their clients' needs which basically emphasize cost, function, and aesthetics. Most architectural practices are trained to provide comfortable spaces by installing mechanical systems for heating, cooling and artificially ventilating buildings, rather than utilizing passive design such as natural

lighting, proper building orientation and the use of sun shading strategies to reduce dependency on mechanical systems that require energy to operate (Butler, 2008).

Architecture 2030 has provided three strategies for meeting their challenge objectives:

- a) Applying passive design approaches such as the proper orientation of buildings on site, daylighting strategies through proper window-to-wall ratios, insulation, proper selection of roofing materials and the overall building form (Su, 2008).
- b) The proper selection of energy- efficient mechanical systems, appliances and low carbon emitting materials.
- c) The implementation of on-site renewable energy generation (Architecture 2030, 2013b).

The solar passive design approaches will be further discussed in Section 2.3

Architecture 2030, along with other international programs, have been established to address the importance of educating architects to design energy efficient buildings in addition to integrating renewable energy technologies within their projects. PV applications in architecture have not yet become mainstream. The reasons for this might be lack of awareness and the absence of environmental design tools among industry stakeholders, specifically architects (Wall, Windeleff, & Lien, 2008). The Solar Heating and Cooling Programme - Task 41, was established in 2009 by the International Environmental Agency (IEA) as an effort to address the challenges facing the integration of PV technology within the building industry. Task 41 'Solar Energy and Architecture', was a three year project that involved architects and researchers from 14 countries across the globe. Task 41 addressed the proper integration of PV systems because PV systems require a large area compared to the area of building envelopes. In order to successfully integrate PV systems within a building envelope without compromising either the building aesthetic or its

performance, architects have to be well educated and well equipped with proper design tools.

Otherwise, the poor integration of PV systems and lack of architectural aesthetics (“style”) may obstruct the social acceptance of the PV technology (Wall et al., 2012).

The scope of this program included residential and non-residential buildings, whether they were new construction or existing buildings. The main objective was to attain high quality architecture for buildings with integrated PV systems. To achieve that; three main areas were targeted (Wall et al., 2008, p.4):

1. “Architectural quality criteria; guidelines for architects by technology and application for new products development”.
2. “Tool development for early stage evaluations and balancing various solar technologies integration”.
3. “Integration concepts and examples, and derived guidelines for architects”.

SHC-Task 41 was completed in 2012 with important key results such as the establishment of two important guidelines for architects: a) “Solar Energy Systems in Architecture Integration Criteria and Guidelines” which sums up the knowledge required to integrate solar technologies within the architectural practice; and b) “Communication Guideline” which provides knowledge about dealing with different stakeholders involved in the process such as clients, contractors and authorities (SHC -Task 41, 2012, p.2).

2.4 Towards Environmentally Responsive Buildings

2.4.1 Introduction

As mentioned earlier in this study, the world’s energy demand has been constantly increasing due to the growth in population and the increased demand of human comfort and standards of living. Buildings consume energy throughout their life span, and studies show that buildings’

operating energy, which is the energy required for a building to properly function and maintain comfort levels for occupants (by providing for heating, cooling, ventilation, appliances, lighting, and hot water system), accounts for nearly 80 percent to 90 percent of the energy consumed during their life cycle (Ramesh et al., 2010). Therefore, designing environmentally responsive buildings that are energy-efficient in use is essential to mitigate adverse environmental effects, resource depletion, and reduce the impact of rising energy prices.

Architects and engineers collaborate to design and construct buildings that are functional and aesthetically appealing. Buildings are considered functional when healthy spaces are created and occupants' comfort is maintained. Intelligent buildings are designed to act as living entities that are adaptive to their local environment, rather than the static structures that most conventional architects are trained to design (Tombazis & Preuss, 2001). In order for designers to achieve environmentally responsive buildings, various passive and active measures and design considerations should be applied. Such measures include special consideration to the building envelope, orientation, window-to-wall area and shading. Applying Building Integrated (BIPV) or Building Applied (BAPV) Photovoltaics, which generate clean electricity, can also help reduce the dependency on non-renewable energy sources.

2.4.2 Passive and Active Solar Design

"I believe that man's yearning for light is natural. In a temperate climate I would not balk at having that light, even the sun itself, flooding the home." (Le Corbusier, 1961, p.38)

Providing access to sunlight has always been an important guideline for architects and designers. Le Corbusier, a famous modernist architect who has designed many iconic buildings, understood the essential human need to be exposed to sunlight, and be protected from it at other times of the

year, by inventing structural sun shading elements known as sun-breakers (Lechner, 2009). Currently, stringent urban regulations in different countries require designers -by law- to provide access to sunlight and daylight in addition to not obstruct sunlight access to adjacent buildings (Morello & Ratti, 2009). However, the need to harness sunlight is not a new concept. Thousands of years ago Vernacular Architecture, a term used to describe the design and construction techniques and traditions used by people who were adaptive to their environment when constructing their dwellings, has shown different examples of how a building can be responsive to its environment (Rudofsky, 1987; Zhai & Previtali, 2010).

Learning by doing, the energy-saving techniques used by people through history are of great interest to many designers today. There are two design approaches to utilize solar energy in heating, cooling and daylighting a building: active and passive solar design. Designers need to consider either active or passive or a combination of both when undertaking a low energy building design.

Active solar heating, for example, is an approach where sunlight heats a working fluid such as water. With the help of mechanical equipment, this heat is distributed to warm spaces or may be stored for future use (U.S. Department of Energy, 2012).

Passive solar design is a simple approach to capture the sunlight without the use of any mechanical systems. No pumps, fans or any working fluids are used when heating or cooling a space (Agrawal, 1989). This means that passive systems require less maintenance and offer a great reduction in the energy demand on non-renewable sources, consequently reducing environmental harm and providing financial savings.

Lechner (2009) explains the architectural approach to sustainability as a three tier approach, seen in Figure 2.2. He explains that the first tier and most important step to achieve an environmentally adaptive design is the architectural design itself. Architects make different choices when designing their projects, and making the right choice about the building's location, orientation, form, material, etc. can reduce up to 60 percent of buildings' energy consumption (Lechner, 2009). The second tier focuses on including passive systems that use natural resources to heat and cool buildings. Direct gain, Trombe wall and sunspaces, which are briefly explained below, are examples of architectural elements that can enhance building energy performance without the necessity to install any mechanical systems. Lechner claims that by applying these passive strategies, designers could save up to 20 percent of building energy consumption. Which means by applying tier 1 and tier 2, architects can save up a total of 80 percent of building energy consumption (Lechner, 2009, p.8).

The third and last tier focuses on choosing energy-efficient mechanical equipment for heating, cooling and lighting. If the design process entails environmentally responsive choices, a huge portion of the energy needed to operate buildings would be saved. In addition, applying on-site renewable energy such as BIPV/BAPV systems, which are the core of this study, generate clean electricity that can be used to operate the building's mechanical systems. The three major passive heating solar systems are: direct gain, Trombe wall and sunspace which are discussed in page 23.

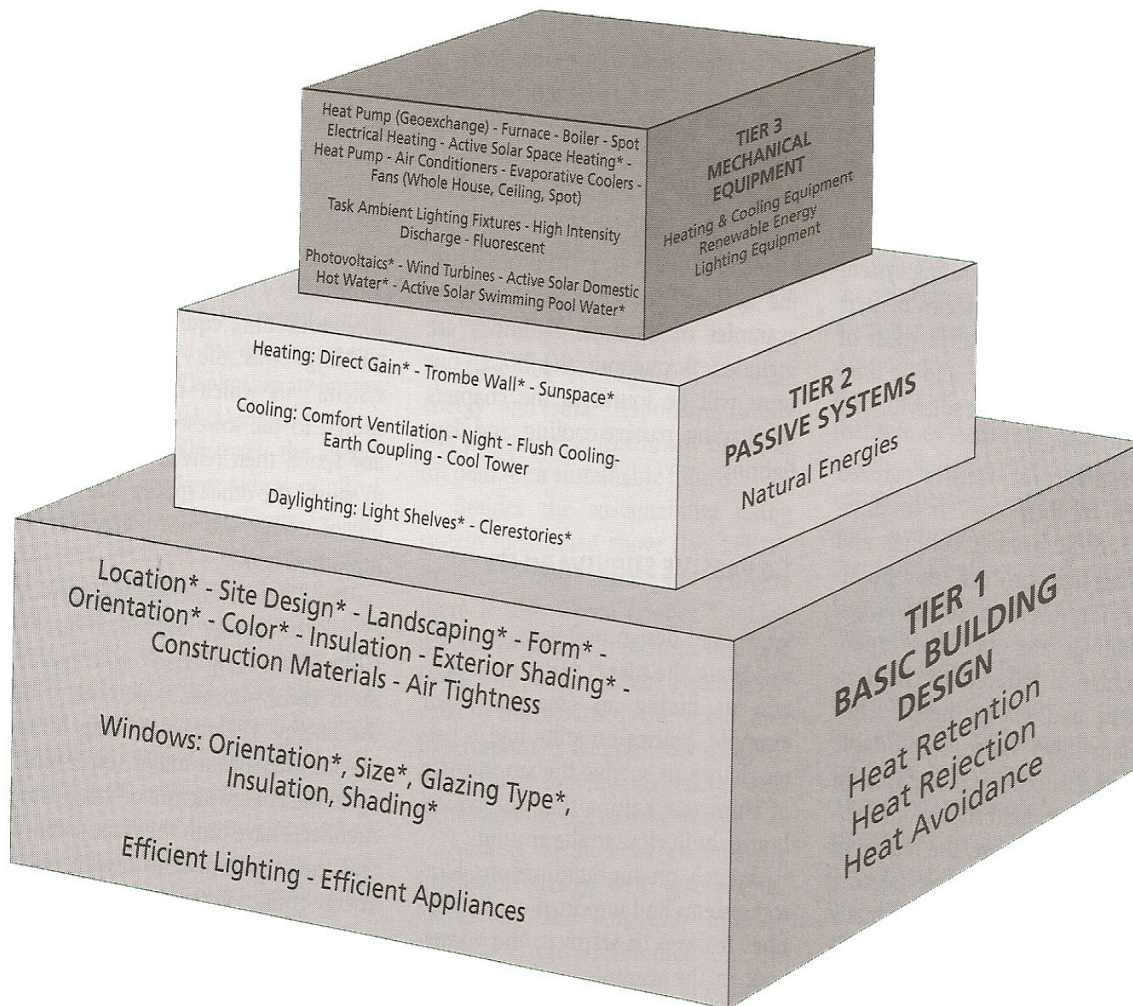


Figure 2.2: The Three Tier Architectural Design Approach.

Source: Norbert Lechner, 2009. Figure 1.4, p. 9

Every passive solar heating system consists of two fundamental components: a collector which is glazing that is applied to the south facing façade, and heat storage which usually consists of a brick wall, a tile floor or any high-mass material to absorb heat (Lechner, 2009). Designers should match the proper passive design technique to the appropriate climate conditions (Mihalakakou, 2002), and can follow the techniques mentioned below to harvest the benefits of the freely available sunlight:

1. Properly orienting buildings on site

The proper orientation of buildings on site is the most essential design feature that can be decided early on and is easily accomplished. Typically, to properly orient buildings on site they must have clear solar access. They are designed to collect sunlight through south-facing fenestration that is ideally within 30 degrees of true south and clear of any obstruction of trees or physical elements (U.S. Department of Energy, 2012). Occasionally, a south orientation is not possible in urban settings. However, it might be of benefit to confirm that an orientation of up to 20-40 degrees east or west of true south still functions properly (Lechner, 2009).

2. The use of large glazing areas to maximize direct heat gain

Windows are the major factor in admitting sunlight into buildings. Special consideration should be given to south facing façades as they can receive approximately three times higher sunlight during the winter compared to other sides (Mazria, 1979). Designers decide on the size of the glazing needed depending on the space function and the amount of solar energy they desire to collect.

3. The use of shading devices.

Windows play a significant role in daylighting, heating, and cooling a building. By applying shading devices, designers can avoid overheating in hot seasons and consequently reduce the need to mechanically cool indoor spaces (Ralegaonkar & Gupta, 2010). There are many different types and shapes, colors and designs of sun shading devices available. Kischkoweit-Lopin, (2002) lists different shading systems and their roles in admitting diffuse daylight and preventing overheating of spaces through blocking direct sunlight. Each system has to be carefully selected to match the goals that designers seek to achieve, otherwise complications such as space overheating or glare may result (Kischkoweit-Lopin, 2002).

The three major passive heating solar systems are:

- **Direct gain systems**

This is a strategy to heat buildings in the winter by designing large fenestration areas that allow the sunlight to penetrate into the building from its south facing façade. Simultaneously, the building's walls and floors are constructed of materials that absorb heat such as brick, concrete and stone (which is referred to as thermal mass). Those building materials retain heat and re-emit it at night, and as a result the desired space stays warm. Various design considerations have to be taken into account when designing a solar passive heat system such as the area of glazing in the south-facing façade, efficiency of the glazing, insulation of the building envelope and the thickness of the building's thermal mass (Lechner, 2009; Mazria, 1979).

- **Trombe wall**

This is a passive solar heating system which requires construction of a thick solid wall of dark-colored concrete or masonry inside a south-facing façade glazing. The system works when the wall absorbs the solar heat during the day, retains it and radiates it in the evening to keep the space warm at night (Koyunbaba & Yilmaz, 2012; Lechner, 2009; Mazria, 1979).

- **Sunspace**

Formerly called a greenhouse or solarium (Lechner, 2009; Mazria, 1979). This space is often used in energy-efficient building designs because it has two benefits: a) it collects heat during the day, therefore decreasing the need for non-renewable energy sources; and b) it usually serves as a living space due to its architectural beauty. It is noteworthy that sunspaces are not ideal for all climates.

2.5 Renewable Energy Sources (RES)

Renewable Energy Sources (RES) represent energy from natural resources such as solar, wind, moving water, biomass, and geothermal, that are replenished within a human lifetime (Natural Resources Canada, 2009a). Increasing the share of renewable energy sources has been a priority to policymakers in many countries. Even though renewable energy systems are still young in the global market compared to fossil fuel systems, they have recently witnessed a substantial growth in several countries (Cucchiella, D'Adamo, Gastaldi, & Koh, 2012). Governments are working to meet the Kyoto Protocol targets by investing in various renewable energy sources. Renewable Energy consumers are also interested in reducing their energy bills and generating revenues in the long run (Cucchiella et al., 2012). For several years, there have been various policies in different jurisdictions around the globe to encourage the adoption of renewable energy sources (RES) (Parker, 2008).

For example, as early as 1994, government financial subsidies were offered to PV consumers in Japan. The “Monitoring Programme for Residential PV systems” was a huge success tripling the annual PV installations (from 539 in 1994 to 1866 installations in 1996). In addition, some local governments in Japan also offered subsidies to share the PV installation cost, in some cases up to 40% (Jäger-waldau, 2002; Parker, 2008). In Europe, Germany is the leader in PV installation since the introduction of the German Renewable Energy Source Act (EEG) in 2000. The EEG feed in tariff policy guaranteed 20 years of purchased electricity from consumers, and stimulated investment in PV installations because it provided consumers with reduced risk and long term financial security (Jäger-waldau, 2002; Mabee, Mannion, & Carpenter, 2012). Australia’s residential rebate, The Solar Home and Community Plan program, provided consumers with a capital rebate for every PV system installed on a residential or a community building, and

encouraged investments in grid connected PV installations. Additionally, the Australian Renewable Energy Target (RET) was initiated in 2001 and operates by creating energy certificates for consumers depending on the amount of electricity produced by PV systems. Consumers can afterwards sell these certificates to retailers and generate revenue. The certificates are classified into large-scale generation certificates (LGCs) and small scale technology certificates (STCs) (Australian Government, 2013; Parker, 2008).

In the United States, diverse policies have been developed at the federal and state level to mitigate Climate Change by promoting the adoption of renewable energy technologies. The most recognized policies are: a) renewable portfolio standards (RPS) through which a certain share or percentage of retailed electricity has to be generated from renewable energy sources; b) guaranteed loans; c) net metering, which allows end users to trade back their generated electricity to the utility grid (by allowing electric meters to operate backwards when consumers generate electricity that exceeds their needs); and d) tax credit programs (Sarzynski, Larrieu, & Shrimali, 2012). A study conducted by Palmer et al. (2011) indicated that as of the third quarter of 2010, the Renewable Portfolio Standards (RPS) policy has been implemented in 29 states in addition to the District of Columbia. At this same date, 43 states in addition to the District of Columbia have implemented a net metering policy. The difference lies in who bears the upfront cost of the renewable energy systems. In the case of RPS, electricity retailers pay upfront costs, while consumers pay for the renewable energy systems in the cases of net metering policy.

In Canada and other countries around the world, different incentive mechanisms have been in place. A Feed-in Tariff (FIT), which is a financial incentive offered by utilities to renewable energy generators as premium payments for their generated electricity that is fed to the grid, have

proved to be a great mechanism to encourage RE adoption (Jäger-waldau, 2002; Parker, 2008). Feed-in Tariff incentive programs are instruments that not only trigger investments, but also promote positive behaviors towards energy consumption. Globally, FITs have been adopted and applied in over 75 jurisdictions (Bertoldi et al., 2013). For example, in the province of Ontario, the FIT program not only provides financial incentives for small and large scale projects, but also provides different pricing for each renewable energy technology, with solar earning the highest rate (OPA, 2013).

Table 2.1 shows the different feed in tariff prices paid for various PV applications in Ontario as of November 2013. There has been a decrease in the tariffs in 2013 compared to the tariffs paid in 2009. The rationale behind reviewing the tariffs every two years is to reflect the PV capital costs and deliver stability to PV investors as the technology matures and the module prices decline (Ministry of Energy, 2012). For example, solar rooftop applications that are ≤ 10 kW are priced at 39.6 cents /kWh in 2013 compared to 80.2 cents/kWh in 2009 (Ontario Power Authority, 2013). This is part of the FIT policy design – rates are intended to decrease over time as the industry scales up and costs decline. Other incentive mechanisms used in Canada at the provincial level are net metering and net billing (Ayoub, Bailey, & Poissant, 2011).

Table 2.1: Ontario FIT 3.0 Prices for Solar PV as of Nov, 2013
Source: (Ontario Power Authority, 2013)

Renewable Fuel	Project Size Tranche*	FIT Price (¢/kWh)
Solar (PV) Rooftop	≤10 kW	39.6
	>10≤100 kW	34.5
	>100kW	32.9
Solar (PV) Non-Rooftop	≤10kW	29.1
	>10kW	28.8

* The FIT Program is available to Small FIT projects; that is, projects generally ≤ 500kW

2.6 Green Building Certification Programs

Multiple tools and building sustainability assessment programs have been developed because of the increased awareness about climate change. Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), Comprehensive Assessment System for Built Environment Efficiency (CASBEE), Building Environmental Assessment Method (BEAM Plus), Green Globes and The Living Building Challenge are all examples of these tools. The reason behind the existence of various assessment programs is that each program often caters to its local context, which might render it not applicable to other geographical regions; however, in their global competition to be acknowledged, some of these programs succeeded in getting more recognition than others and spreading internationally. It is worth mentioning that each certification program is distinctive in its certification criteria; however, several aspects play a role in the assessment process such as the climate, construction materials, and renewable energy potential (Alyami & Rezgui, 2012).

Leadership in Energy and Environmental Design (LEED) and the Building Research Establishment Environmental Assessment Method (BREEAM) are two of many green building rating programs that have gained acceptance globally. Both rating systems operate by setting benchmarks in different categories. Each category addresses an area of improvement to the building design that enhances it, such as a reduction in GHG emissions, improved indoor air quality, water conservation, energy efficiency or wastewater management. Points/credits are assigned to each category to measure the level of achievement, higher point/credit counts implies a more environmentally adaptive design.

Both tools share many features such as being designed to include different buildings categories that are subdivided into various environmental targets (See Table 2.2); however, BREEAM has adopted a weighing system to assess the sustainability of buildings and emphasizes the need to reduce greenhouse gas emissions. LEED on the other hand requires a percentage of energy cost improvement compared to the reference case rather than the associated emissions (Canada Green Building Council, 2010; Lee & Burnett, 2008). It is more appropriate for climates that depend on mechanical ventilation and automotive use. LEED certified buildings rated Silver or Gold are reflected to have low energy performance under BREEAM (Schwartz & Raslan, 2013, p.351).

Table 2.2: Comparative Overview of BREEAM and LEED
Source: (Schwartz & Raslan, 2013), Table 1, page 351.

	BREEAM 2011	LEED 2009
Certifying body	BRE – British Research Establishment	USGBC – U.S Green Building Council
Scope of accredited buildings	Over 200,000 buildings	Nearly 45,000 commercial buildings Nearly 19,000 certified residential units and 75,000 registered residential units
Schemes	New construction Refurbishment Code for sustainable homes Communities In-use	New construction and major renovations Existing buildings Commercial interiors Core and shell Schools Retail Healthcare Homes Neighborhood development
Latest version (new construction)	BREEAM New Construction 2.0:2011	LEED 2009 New Construction and Major Renovations (updated November 2011)
Main parameter for reduction	Annual CO2 emissions	Annual energy cost ¹
Categories, available credits and weights (where applicable)	Management 22 (w = 12) Health and Wellbeing 10 (w = 15) Energy (Ene) 30 (w = 19) Transport 9 (w = 8) Water 9 (w = 6) Materials 12 (w = 12.5) Waste 7 (w = 7.5) Land use and ecology 10 (w = 10) Pollution 13 (w = 10) Innovation 10 (w = 10)	Sustainable site 26 Water efficiency 10 Energy and atmosphere (EA) 35 Materials and resources 14 Indoor environmental quality 15 Innovation in design 6
Rating scale (%)	Outstanding >85 Excellent 70 Very good 55 Good 45 Pass 30 Unclassified <30	Platinum >80 Gold 60–79 Silver 50–59 Certified 40–49

The adoption rate of such certification programs is increasing. In May 2013, Canada celebrated 1000 LEED certified projects ranging from single family homes, schools and arenas to industrial complexes. Currently, Canada contains the second largest number of LEED certified projects in the world after the U.S. (Canada Green Building Council, 2013, para 2). The literature suggests

¹ “The energy analysis done for the building performance rating method must include all the energy costs associated with the building project” (Canada Green Building Council, 2010, p.42).

that the existence of these programs has helped in reducing the energy demand in LEED buildings whether they are new construction or a retrofit (Schwartz & Raslan, 2013).

The United States Department of Energy reported that LEED-Gold rated buildings have nearly 25 percent lower energy consumption and 19 percent less operational energy requirements compared to the national average (U.S Green Building Council, 2012).

Katz (2011), a director of corporate communication and marketing at the U.S. Green Building Council claims that: “Projects worldwide are proving that green building doesn't have to mean building new. By undertaking a large renovation, the recently LEED-certified Empire State Building has predicted it will slash energy consumption by more than 38 percent, saving \$4.4 million in energy costs annually, and recouping the costs of implementation in only three years” (Katz, 2011, para 5).

However, Scofield (2013) argues that not all LEED rated buildings perform equally well in terms of energy efficiency. According to his results from comparing energy data for 21 LEED certified NYC buildings to non-LEED certified ones, “...LEED buildings certified at the Gold level outperformed other NYC office buildings by 20%. In contrast LEED Silver and Certified office buildings underperformed other NYC office buildings.” (Scofield, 2013,p.517) This suggests that further studies need to be conducted to define the minimum energy performance under each LEED rating/level.

2.7 Photovoltaics and Architecture

2.7.1 Photovoltaic Technology

Photovoltaic (PV) is a technology that utilizes abundant solar radiation to generate electricity directly. "Photovoltaic", as a term, consists of two words: photo, which is derived from the Greek origin and means light, and volt which is the basic unit to measure electricity and is associated with the research pioneer Alessandro Volta (U.S. Department of Energy, 2013). PV modules consist of multiple PV cells that are manufactured of semi-conductor materials such as silicon (Tyagi et al., 2013). Silicon ingots are sliced into circular or square wafers, which in turn are used to manufacture PV cells (Green, 2000). Since PV modules have no moving elements and do not require any fuel to operate, they are a technology that generates clean energy with no greenhouse gas emissions in use (U.S Department of Energy, 1997). PV technology is well recognized as it has been in practice for approximately 50 years in many different applications, and over 20 years for grid connected applications (Bazilian et al., 2013).

According to the U.S National Renewable Energy Laboratory (2012), the different types of PV cells are:

- Traditional or first generation photovoltaic cells. Those cells are manufactured from silicon, and commonly used due to their high module conversion efficiency compared to other PV cells. Conversion efficiency of photovoltaic (PV) cells is defined as the percentage of the sunlight that is converted into electricity (U.S Department of Energy, 2013). Developing PV cells that are high in conversion efficiency is an important goal to energy researchers since this helps in achieving a cost-competitive technology compared to conventional or non-renewable

energy sources. Examples of first generation PV cells are mono and polycrystalline silicon and gallium arsenide (GaAs).

- Second-generation photovoltaic cells or “thin-films”. The reason behind calling these cells thin films is due to fact that they are manufactured by depositing very thin layers of semiconductor materials such as amorphous silicon or cadmium telluride (CdTe) and copper indium gallium selenide (CIGS). Thin films can be used in innovative designs of building facades or skylights due to their flexibility in both their physical characteristics and their various applications.
- Third-generation photovoltaic cells are manufactured of non-silicon materials such as dye-sensitized, organic polymer, or hybrid PV cells that are a mixture of crystalline silicon and non-crystalline silicon (Tyagi et al., 2013). These materials are relatively more expensive than silicon, but due to using very small amounts in PV cells, they are becoming affordable.

Figure 2.3 illustrates the highest conversion efficiencies for different generations of PV cells as recorded by the National Renewable Energy Laboratory (NREL). The Figure shows, for example, that multijunction cells have a conversion efficiency of 44.4 percent for three junction (concentrator) cells, which is the highest efficiency among all reported PV cells, whereas quantum dot cells have a low conversion efficiency of 7 percent. Each type of the above mentioned PV cells has its distinctive characteristics.

In terms of module appearance, PV modules are usually dark in color, with the shade depending on the use of an anti-reflective coating that decreases the amount of reflected sunlight (Roberts & Guariento, 2009).

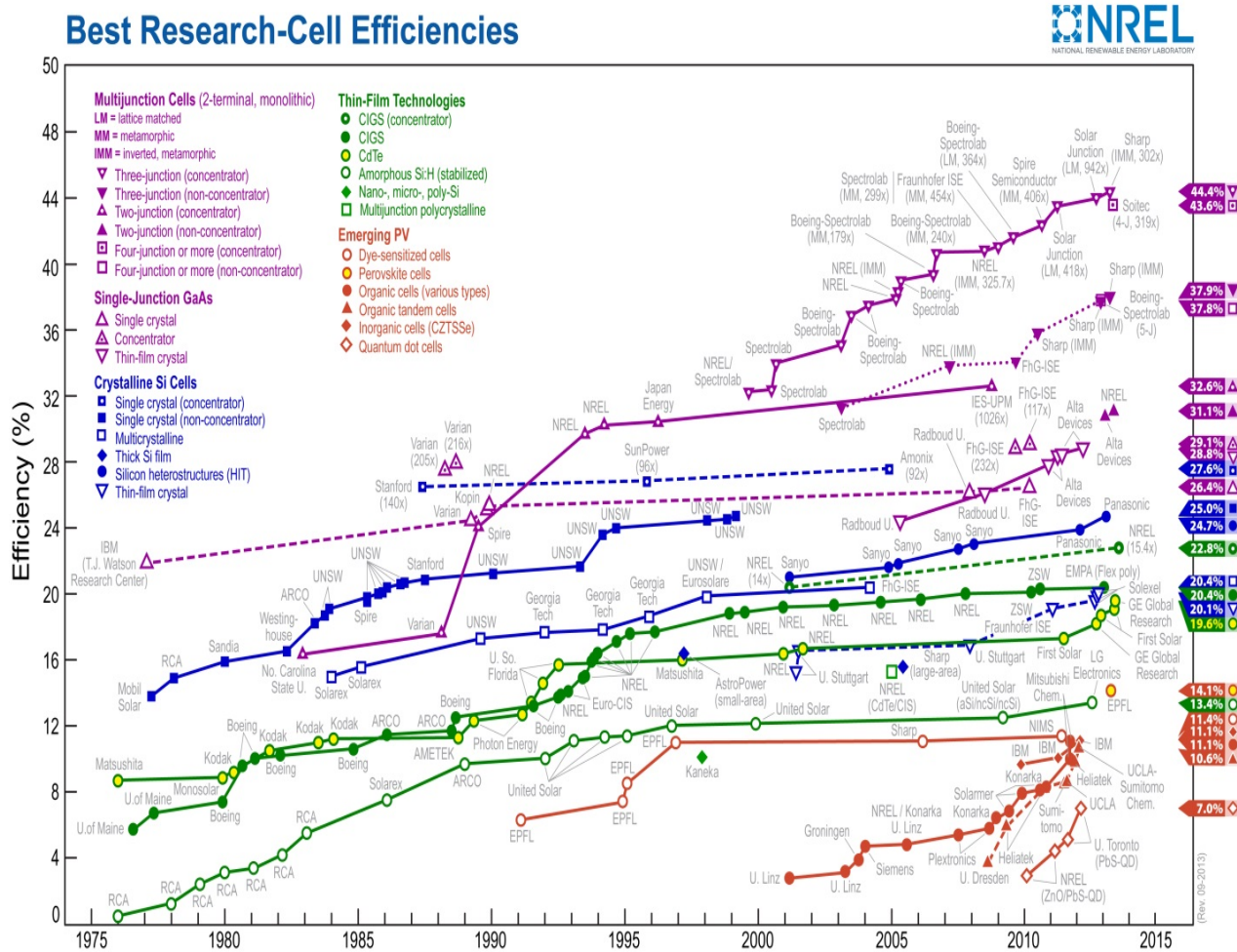


Figure 2.3: Cell Conversion Efficiency
Source: NREL, 2013

Monocrystalline cells are black to dark grey or blue with visible cell patterns, Polycrystalline cells are typically dark blue, whereas thin films are often dark reddish-brown in color and can be manufactured to be semi-transparent (U.S Department of Energy, 1997). Currently, crystalline silicon modules are widespread and preferred in the market due to their maturity, availability of products that can be integrated within the building envelope, and most importantly, the higher conversion efficiency compared to thin film technologies (Bambara, 2012).

In terms of economics, PV module prices have dramatically declined since 2008. For example, in Canada, module prices (weighted average) C\$/per watt have declined from C\$10.70 in 2000 to C\$2.27 in 2010; which indicates a price decrease of approximately 16 percent annually (Ayoub et al., 2011). In the U.S, PV installed prices continued to decline in 2012 and the first half of 2013. In a study done in July 2013 by Lawrence Berkeley National laboratory, PV installed prices continue to decline year over year by US\$0.90/W for systems $\leq 10\text{kW}$ and US\$0.80/W for systems 10-100kW and US\$0.30/W for systems that are $>100\text{kW}$ (Barbose, Darghouth, Weaver, & Wiser, 2013, p.1). If this trend continues, PV module cost will become competitive with conventional electricity purchased from utility grids that are powered by non-renewable sources. Reichelstein & Yorston (2013) claim that solar photovoltaic for utility scale applications will become cost competitive by the end of this decade. However, other scholars such as Bazilian et al.(2013) suggest that it is hard to tell if the price will be competitive with conventional electricity sources because based on the data available in 2011, he claims that there is lack of transparency in PV costs among different stakeholders in the PV industry. Therefore, future PV costs trajectories can be difficult to establish with the available data.

2.7.2 Photovoltaics Applications in Architecture

As mentioned above, different module types have different applications in architecture due to their performance, geometry, dimension, and aesthetic qualities. For example, PV modules can be used either on a stand-alone structure or can be applied/integrated within the building envelope. Building Applied Photovoltaic modules (BAPV) are applied to existing or newly constructed buildings. They provide no architectural function in the building, and are considered an add-on. They are usually visible, limited in their architectural applications compared to integrated PV modules and are applied, either as standoff or rack-mounted, solely to generate

electricity (Peng, Huang, & Wu, 2011). Standoff PV modules are applied directly above the roof surface and follow a similar slope as the pitched roof, whereas rack-mounted arrays are usually installed on buildings with flat roofs and can be tilted and oriented as desired. The array superstructure is usually secured to the roof structure to ensure that the array withstands wind and dead loads (Barkaszi & Dunlop, 2001).

Figure 2.4 shows the Canadian Centre for Housing Technology roof that has both BAPV system -to the left- and BIPV integrated into the roof -to the right. It also shows that PV modules can be applied above windows to function as sun-shade devices. This joint initiative between National Resources Canada and Canada Mortgage and Housing Corporation aims to test both the performance and durability of PV systems in residential roofs.



Figure 2.4: Canadian Centre for Housing Technology.
Source: National Research Council Canada, 2013.

Building Integrated Photovoltaic (BIPV) on the other hand is more aesthetically appealing, because it can be seamlessly integrated within the building envelope and serve a dual function of replacing a building component such as roofing, windows, or skylights, and generating clean electricity simultaneously (Bambara, 2012; Keoleian & Lewis, 2003). Since BIPV is an inseparable part of the building's envelope or structure, it does not require any extra area of land or any racking system to support it (Barkaszi & Dunlop, 2001; Keoleian & Lewis, 2003). Figure 2.5 demonstrates the use of BIPV in the Greenstone Government of Canada building in Yellowknife, NWT. PV modules have been seamlessly integrated within the curtain wall modules. In 2007, Greenstone received a LEED-Gold standard certification as well as the 2007 RAIC Award of Excellence in Architecture and Innovation-science category (The Royal Architectural Institute of Canada, 2007).



Figure 2.5: BIPV curtain wall of the Greenstone Government of Canada Building in Yellowknife.

Source: Manasc Isaac Architects, 2007.

BIPV history goes back to the 1970s, but was not accepted until the 1990s when PV technologies became more efficient and reliable (James, Goodrich, Woodhouse, Margolis, & Ong, 2011; U.S Department of Energy, 1997). Most BIPV projects in the 70s were financed by governments to examine the technology. For example, in the United States the Department of Energy (DOE) funded three projects in different jurisdictions to test the modules in different climates (Arthur D. Little Inc., 1995). In Japan, interest in utilizing PV technology began after the first oil crisis with the introduction of the Sunshine project in 1974, the Moonshine in 1980 and the new Sunshine in 1993 to reduce the dependency on oil energy sources (Parker, 2008). Additionally, interest in PV continued due to the increased efforts to mitigate climate concerns and meet the Kyoto targets. It is important to emphasize that Japan is limited in land area compared to Canada and the U.S; therefore the opportunities to invest in large area PV farms are limited. Instead, integrating PV within buildings and/or placing PV modules on the tops of buildings are preferred options.

For example, in 1990 the German government succeeded in implementing their first mass PV installation, known as the “1000 Roofs” program, by reimbursing 70 percent of PV system costs (Arthur D. Little Inc., 1995). Germany has excelled in integrating different PV products within the building envelope. The first application of a BIPV curtain wall façade took place in Aachen, Germany. BIPV has grown in the German solar market due to its functionality and the financial savings gained from replacing a building component. BIPV façades cost only an additional US\$350-500/m² compared to the cost of traditional facades, without taking into account the environmental and economic gains (Benemann, Chehab, & Schaar-Gabriel, 2001). BIPV products can be either standardized or customized to cater to customers and architects’ taste.

Every project is distinctive in terms of how BIPV is integrated, depending on building orientation, or roof inclination, or even the area of spaces where modules are applied. The potential for the diffusion of BIPV products in the market is huge, as many companies and R&D bodies are working to develop commercialized PV systems that can easily replace a building element even if their costs slightly exceed the conventional price for the replaced element. Economics are not the sole criterion that plays a role in architectural decisions, as intangible values such as aesthetics, quality of indoor spaces and overall building performance hold a great value that can, in some cases, surpass the importance of economics (U.S Department of Energy, 1997).

BIPV is described as a “commercially preferable, environmentally benign, aesthetically pleasing way of generating electricity for commercial, institutional, and many other kinds of buildings” (Eiffert & Kiss, n.d., p.3). As with any new product or technology in the market, essential knowledge of PV needs to be transferred to the people who will integrate it within their designs. Architects and designers need to be aware of and educated about PV to develop distinctive architectural products that can serve their design purpose and elevate buildings’ performance.

2.8 Previous Studies and the Literature Gap

After the German Renewable Energy Act, a law to subsidize renewable energy by providing different incentive programs to encourage the diffusion of clean energy sources, was passed in 2000, PV applications were widely spread in Germany, the biggest PV market in Europe (Grau, Huo, & Neuhoff, 2012; Tyagi et al., 2013). Financial incentives such as feed-in tariffs and the political support for renewable energy technologies helped in pushing the PV technology forward. Studies conducted in the German context show that there is a positive relationship

between BIPV installed capacity and the availability of flexible financial incentives (Wood, 2006). However, Peng et al. (2011, p.3597) claim that the lack of financial incentives in China is not the main reason behind the lag of PV technology installations there, but rather the lack of standardization, installation and maintenance knowledge as well as the inconvenience of repairing and replacing a BIPV component. Thus, different key barriers have been identified in the literature, but it is worth mentioning that PV barriers are context specific, which means that they are different from one country to another and perceived differently among different industry players. The following studies demonstrate the different PV barriers identified in the literature:

Candelise, Winskel, & Gross (2013), stated that PV panel cost has been falling since the 1970s, due to PV manufacturing improvements, and the market growth of PV products. Yet, other associated costs such as installer/developer profit, system installation labor and sales tax are highly variable (Friedman, Ardani, Feldman, Citron, & Margolis, 2013). These costs may influence the BIPV/BAPV adoption decision. Zhang, Song, & Hamori (2011) found out that PV installation costs have a negative impact on the diffusion of PV technology in Japan.

In North America, different PV barriers and constraints have been identified in the media and literature. Fisher (2006) conducted a study in the Eastbridge neighborhood in Waterloo, Ontario to identify the motivations and barriers affecting consumers'/homebuyers' decisions when purchasing green homes. She claims that prospective green homebuyers seem to be influenced by economic factors the most. However, other non-economic factors play a role in consumers' decision such as marketing strategies and providing adequate information to buyers, offering times and consumers' aesthetic preferences and lifestyles (Fisher, 2006).

Falkenstein (2008) claims that multiple factors may play a role in discouraging homeowners from deploying PV systems, such as the high cost of BIPV/BAPV modules and the lack of financial incentives. Other perceived barriers identified are poor public and industry awareness, lack of installation knowledge and experience, difficult building permitting process, or a combination of all the above (Thomas, 2012).

IEA-SHC Task 41, which is a 3 year project carried out by the International Energy, team conducted interviews with different Scandinavian architectural practices to identify the design process barriers faced when including a PV system within their schemes. Their findings indicated that architects' design tools need further enhancement to include solar technologies at an early design stage, yet must stay compatible with the current flow of the architectural design processes (Kanters, Horvat, & Dubois, 2012).

On one hand, Abidin (2010) conducted a field study to investigate the level of awareness among Malaysian developers regarding their awareness and interest in sustainable practices. His findings indicated that small scale developers' knowledge, experience, and resources vary widely compared to large scale developers and their willingness to pursue sustainable practices is limited. On the other hand, Mosik et al. (2013) stated that 94% of Malaysian young architects (n=31) are aware of BIPV technology and its benefits. However, 77% of respondents have never integrated PV within their buildings (Mosik, Sediadi, & Hamid, 2013).

Pasqualetti & Haag (2011) assessed the education and training for solar PV in the American Southwest, among different industries and educational facilities. Their findings revealed that universities and workplaces need to introduce/increase solar training and education sessions in order to raise awareness among solar industry stakeholders.

PV LEGAL, a 3 year project funded by Intelligent Energy Europe, aimed to identify the administrative barriers that restrain PV diffusion in Europe (Garbe, Latour, & Sonvilla, 2012). The findings indicated that PV paperwork and permitting fees pose a challenge to PV technology dissemination. They recommend that by streamlining and simplifying the administrative procedure, the chances of deploying PV systems would be greater.

PV GRID, a two year project that was initiated in 2012 aims to detect the regulatory and administrative barriers in 16 European countries (Sonvilla, Zane, Poblocka, Brückmann, & Vandenberg, 2013). The project's initial report indicated that the permitting procedures that include PV installation permits, electricity production licences, and grid access and capacity issues are considered major barriers to the diffusion of PV technology (Sonvilla et al., 2013, p.6).

This study focuses on understanding the level of awareness and interest that Canadian and American architects, as major industry stakeholders, have regarding integrating PV technology within their projects. It also explores the different barriers responsible for inhibiting their adoption. This research is designed to provide answers to the research questions in Section 1.3. While other studies have investigated industry stakeholders such as developers and consumers; this study investigates architects as consultants/facilitators and the reasons why BIPV/BAPV is not yet a mainstream design solution among architects in North America through shedding light on the barriers responsible for the lag in technology adoption.

3 METHODS

3.1 Research Design

The purpose of this chapter is to discuss, in detail, the methods used to answer the research questions outlined in Chapter 1, Section 1.3 and repeated here:

1. To what extent are Canadian and American architects aware of BIPV/BAPV technology benefits?
2. To what extent are they willing to consider the deployment of BIPV/BAPV products within their projects?
3. What are the major barriers that might influence their decisions to adopt a BIPV/BAPV system?

A mixed method of qualitative and quantitative approaches is applied in this study to address the research questions. On one hand, the researcher decided to use a quantitative approach to measure and quantify findings in order to be able, if applicable, to generalize them to a larger population of architects. Generalisation of results could be possible, in some cases, because of the random sampling techniques used to recruit respondents. On the other hand, a qualitative approach is also applied to understand the various experiences and behaviours of participants. Conducting in-depth interviews with selected participants is an appropriate way to understand the depth of their views and stories (Hennink, Hutter, & Bailey, 2011, p.16).

Initially, the researcher divided the data collection process into two phases. In the first phase, an online survey questionnaire was sent to Canadian and American architectural practices that have a valid membership in The Royal Architectural Institute of Canada (RAIC) for Canadians, and The American Institute of Architects (AIA) for Americans. A quantitative approach was used to collect data from a large number of architects regarding their awareness level about BIPV/BAPV technology, their interest in applying the technology within their schemes, and their preferences of the building components they wish to replace with PV.

In phase two, in-depth interviews were conducted with two categories of participants: a) architects who were short-listed from the online survey and indicated their willingness to further discuss their BIPV/BAPV experience; and b) key informants at national research and development laboratories and solar industry associations.

According to the description of the research design above, this research applies a sequential mixed methods strategy. Creswell (2009) explains that a sequential mixed method is pursued when the researcher strives to further understand and elaborate on the results attained from one approach by applying an additional one. Therefore, a study may begin with a quantitative approach (as described above) where information is gathered in large quantities and followed by a qualitative approach that focuses on acquiring further information and elaboration from certain individuals (Creswell & Plano-Clark, 2003; Creswell, 2009).

Figure 3.1 illustrates the sequential explanatory design process applied in this study as described by Creswell & Plano-Clark (2003). Following this model, the researcher, after conducting a quantitative approach (the survey questionnaire), identified certain results that needed further elaboration, such as short-listed architects' experiences and any potential barriers they faced when they deployed BIPV/BAPV systems. The researcher then conducted in-depth interviews to further investigate the findings identified earlier in the survey.

Explanatory Design

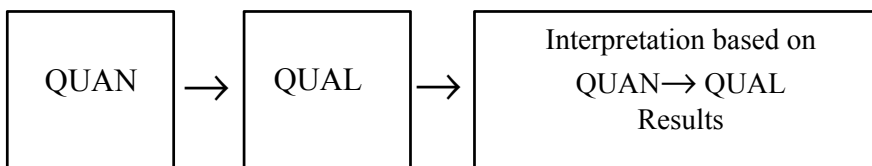


Figure 3.1: The Explanatory Design Process
Adapted from: Creswell & Plano-Clark , 2003

3.2 Research Context

3.2.1 Study Location

This study targets two geographical locations, Canada and the U.S. The reasons behind selecting these two locations are:

- Canada and the U.S. are both among the ten highest countries around the globe in their CO₂ emissions per capita. As recorded in 2011, Canada's emissions are 15.50 tCO₂/cap whereas the U.S. emissions are 16.78 tCO₂/cap respectively (World Energy Council, 2011). These countries are thus among those with the most to gain from employing strategies, such as BIPV/BAPV, that reduce their GHG emissions.
- The U.S. and Canada are the third and fourth highest countries around the globe in their household electricity use in 2011 (World Energy Council, 2011). One of the reasons for this high electricity consumption is the low electricity prices in both countries compared to the rest of the world. Figure 3.2 shows electricity prices, in USD, in different countries around the world. It also shows that in 2011, the average electricity price in Canada was 10¢/kWh, and 12¢/kWh in the U.S., compared to the average price of 35¢/kWh in Germany, and 41¢/kWh in Denmark.

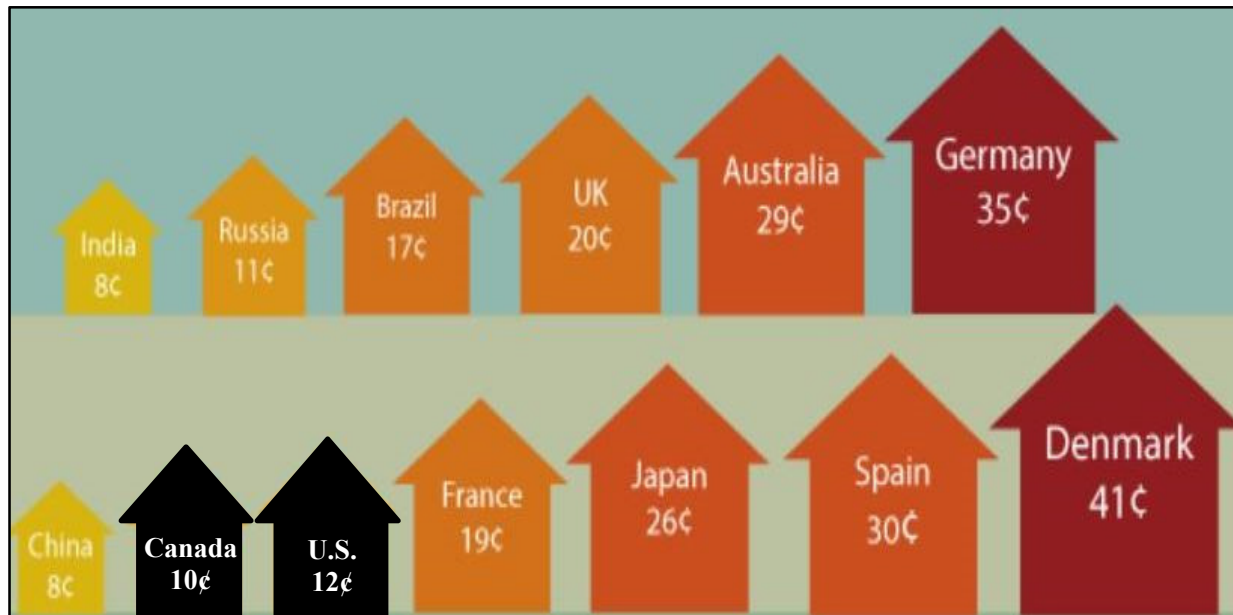


Figure 3.2: Average National Electricity Prices in US cents/kWh

Source: Wilson, 2013, para 1. Obtained from IEA, EIA, OANDA and National Electricity Boards.

- Both countries enjoy political democratic systems that support the adoption of new technologies. Canada and U.S. are trading partners, with large electricity trading across their border. Both countries share a common language, and to a certain degree similar government policies and building standards.
- Both countries offer various financial incentives that encourage renewable energy technology adoption. Finally, Canada has a small number of BIPV projects compared to BAPV ones, so to construct a more globally representative sample the researcher broadened the scope and included American architects in order to enhance the chances of obtaining a perspective of both BIPV and BAPV projects.

3.2.2 Study Population

This study targets a specific sub-group of the total population. As mentioned in Chapter 1, this research investigates architects' awareness and interest in acquiring or implementing BIPV/BAPV systems. Furthermore, it investigates the potential barriers that may affect architects' decisions to adopt PV systems. Architects, as key players, have a great influence on the integration of PV technology within buildings. They have been selected for their significant contributions to the building industry. Additionally, architects are professionally trained to see the big picture, work with different industry stakeholders such as engineers, builders and clients. They are also trained to envision the end results before projects are built and are constantly working on improving their designs. Architects are able to design and supervise various building scales and a wide range of residential, commercial and institutional buildings. They adhere to codes and standards and collaborate/coordinate with different disciplines to achieve their goals and visions (AIA, 2013a).

Further, "...architects serve as trusted advisors, their role is holistic, blending diverse requirements and disciplines in a creative process, while serving the public interest and addressing health and safety matters." (RAIC, 2013, para 1)

The architectural quality of buildings with an integrated PV system is critical to achieving market penetration and PV technology acceptance by end users. By focusing on architects' education and awareness and improving their design and construction methods, higher architectural quality and energy performance can be achieved (SHC-Task 41, 2009).

In the United States, the leading professional membership association is the American Institute of Architect (AIA). They serve as advocates for the architectural practices in the U.S., in addition to their responsibility for setting industry standards and assisting architects in obtaining and preserving their licensure (AIA, 2013b, para 2).

In Canada, architects' associations are provincial, and each province is responsible for regulating the profession and licensing its architects according to their own professional requirements.

However, all provincial architectural associations are under the umbrella of the national professional membership association, The Royal Architectural Institute of Canada (RAIC). The most significant role of RAIC is to serve as a unified voice for architectural practices on a national level. RAIC advocates for improving the quality of the built environment, encourages green architecture and helps architects achieve excellence in their profession (RAIC, 2013b, para 1,3).

In this study, the publically accessible AIA and RAIC online membership directories have been utilized to recruit architects in the U.S. and Canada. Both membership associations were contacted to obtain a list/registry of professional architects who have a valid membership in the RAIC for Canadian architects and the AIA for American architects. The researcher contacted every provincial architectural association in Canada to access their membership lists and compile them all in a master national list. However, the attempts to obtain the lists failed and the researcher was advised by provincial associations to construct a list of architects utilizing the RAIC online directory, which includes members/architects from all provinces across Canada.

3.3 Data Collection Methods

3.3.1 Web-based Survey Questionnaire

The first method used in collecting the data for this study was a web-based survey questionnaire. The survey targeted American and Canadian architects who have an active membership in the AIA for American respondents and in the RAIC for Canadians. Listed below are the reasons behind selecting a web-based survey questionnaire as a preferred method to address the research questions.

- Online surveys help researchers gain access to a targeted group of participants that are hard to reach by other channels of communications (Wright, 2005). For the sake of this study, architects were contacted utilizing a web-based tool that works well with their busy schedules.
- The online survey helped the researcher reach a large number of respondents in the target population despite their dispersed geographical locations. This method saves time and covers a broad spectrum of architectural specialities (Couper, 2000; Wright, 2005).
- In general, online surveys save paper and postage cost, they are fast and give respondents plenty of time to answer the questions at their own pace and without any pressure (Schuldt & Totten, 1994).

The literature also points out different constraints associated with web-based surveys, such as sampling and coverage errors and low response rates compared to other data collection mechanisms (Couper, 2000). Sampling and coverage errors come from the assumption that the population frame is finite. Often researchers obtain lists for certain members of the population that share the same characteristics. It is worth pointing out that many firms restrict the use of their email addresses on the web, and might be automatically excluded from the study population

(Schuldt & Totten, 1994; Wright, 2005). Nonresponse errors and low response rates are also major constraints when conducting web-based surveys due to the fact that respondents might not be interested in participating if the quality of the survey is weak or if the questions are too numerous and/or too long. Furthermore, respondents may face some technical difficulties accessing the web or filling out a survey compared to the familiarity of using a pen and a paper (Couper, 2000).

To overcome such constraints, the researcher designed a survey that took approximately 10 minutes to complete. The survey was designed with multiple-choice questions, in addition to providing respondents opportunity to add explanatory comments if they wished. The researcher encouraged respondents to either pick their preferred answer or provide an answer that was not listed among the choices, or elaborate on their choices.

To enhance the survey response rate, the researcher designed a standardized web survey with personalized invitation messages to each respondent. Furthermore, the first page of the survey contained a cover letter that explained the objectives and importance of the study as an effort to capture respondents' attention and encourage them to participate.

▪ **Survey Design**

The web-based survey was constructed to help the researcher answer the research questions. For example, in order to measure the level of architects' interest in deploying BIPV/BAPV systems; respondents were asked if they are interested in applying photovoltaic systems in their future projects. If their answer was (Yes), they were asked afterwards to choose the buildings components they preferred to replace with PV (See Appendix A).

The researcher designed the survey following Dillman et al. (2009) survey guidelines in order to establish effective questions that could be easily understood and completed in a timely manner.

Examples of the general guidelines used when designing the questions are:

- Identifying the exact type of information needed from respondents.
- Avoiding many open-ended questions. This is a good strategy in survey designs, because open-ended questions usually require a good amount of time from respondents to answer. Open-ended questions may decrease the survey response rate as a result.
- Using simple language with complete sentences.
- Limiting reminder emails to three reminders, more than three reminders is considered, in most cases, disturbing.

The survey was pilot tested by the researcher as well as with two colleagues who are practicing architects. The feedback from the pilot test regarding clarity, style and the time needed to answer questions was positive.

3.3.2 In-depth Interviews

In-depth interviews are conducted when a researcher seeks out detailed information about certain individuals from the study population. During an interview, the researcher asks questions and allows participants to share their experiences and opinions (Hennink et al., 2011). One of the strengths of in-depth interviews is that both the researcher and the interviewee are engaged in a flexible conversation that contains semi-structured questions. That condition often leads the researcher to ask spontaneous, yet useful questions that might be helpful in understanding interviewees' perspectives. In this study, two categories of individuals were contacted: short-

listed architects who expressed their interest in discussing their experiences; and key informants from various national research and development bodies and solar industry associations.

▪ **Short-listed Architects Interviews**

The researcher conducted in-depth interviews with architects in both Canada and the U.S. in order to further understand their motives behind acquiring a PV system, their interest and awareness about the different products, as well as the challenges they faced. Architects were asked about the design process they followed, and if it was different in any phase of the design to accommodate the deployment of PV systems. Further details about the participant recruitment process and sample sizes are discussed in Section 3.4.2.

▪ **Key Informant Interviews**

In order for the researcher to gain a comprehensive perspective about the multiple barriers responsible for slowing down the diffusion of BIPV/BAPV technology in both Canada and the U.S., various key informants were interviewed. Two of the most influential types who connect academic research to professional experience in the solar market are: a) national research and development bodies; and b) solar industry associations.

In Canada, the researcher contacted CanmetENERGY which is a division of Natural Resources Canada and a Canadian leader in research and development on energy efficiency and clean energy sources. CanmetENERGY works with the federal government and energy industries to enhance energy efficiency, codes, and regulations, in addition to energy policy development (Natural Resource Canada, 2009, para 1-3). Furthermore, the researcher contacted the Canadian Solar Industry Association (CanSIA), a national trade organization representing nearly 650 solar businesses all over Canada. CanSIA promotes the adoption of clean technologies and works on

connecting and raising awareness among various industry players (Canadian Solar Industry Association, 2013).

In the United States, the researcher contacted the National Renewable Energy Laboratory (NREL) and the American Solar Energy Society (ASES). NREL is the main research laboratory for the U.S. Department of Energy at the national level and it has a comprehensive vision to develop and promote various renewable technologies in conjunction with raising awareness and educating industry players (National Renewable Energy Laboratory, 2013). ASES is the national industry association in the U.S. and aims to promote energy efficiency and works on building sustainable communities. ASES sponsors many solar programs that help raising awareness among homeowners, school students and industrial key players, on top of its award winning solar magazine that features leading technologies and products.

Key informant recruitment process and the total number of participants interviewed are discussed in Section 3.4.2.

3.4 Participant Recruitment Process

3.4.1 Web-based Survey Questionnaire

As discussed in Section 3.3.1, the first phase of this study included the administration of a web-based survey questionnaire. The researcher constructed two lists (using Microsoft Excel) of architectural practices utilizing the online membership directories of the AIA and RAIC: an American architects list; and a Canadian architects list.

The list of American architects contained a sample frame of 14,193 potential respondents, whereas the Canadian list contained a total of 3,460 potential respondents. The architects were of

different specialities, ranging from single-family residential to commercial and institutional buildings. The AIA online member directory, in some cases, displayed duplicate records of members since they are listed by speciality and each member may have multiple specialities. The researcher made sure that the final list did not contain any duplication of respondents. To avoid bias in drawing the sample, the researcher conducted a random sorting of the lists followed by random selection of survey potential respondents.

In statistics, to calculate a sample size, two important factors have to be determined: the confidence interval or “the margin of error”; and the confidence level which is an indicator of how representative the sample is of its population. In social sciences and most human dimension studies a confidence level of 95% and a confidence interval of $\pm 5\%$ are broadly used (Vaske, 2008).

Table 3.1 contains results of sample size calculations at three confidence intervals and two different population splits (50/50 and 80/20). The population split is an indication of the homogeneity or heterogeneity of the sample, where 50/50 split is an assumption that the sample is fairly heterogeneous in their characteristics and an 80/20 split is an assumption that the sample is homogeneous. Assuming that a lower margin of error is desired such as $\pm 3\%$, the sample size would be too large (See Table 3.1), at the same time if the researcher chose a higher margin of error such as $\pm 10\%$, the number would be insufficient to produce a representative sample. Therefore a confidence level of $\pm 5\%$ deemed the most suitable. The 50/50 split shown in Table 3.1 indicates that the population responses are split equally. In other words, if half of the population answer a question in a certain way, such as (they agree or disagree, for example); the other half of the population answers in the opposite way (Vaske, 2008).

Table 3.1: Web-based survey calculated sample sizes at three levels of precision, following Dillman et al. (2009, p.57) and as also explained by Vaske (2008, p.180)

	Sample Frame	Sample Size $\pm 10\%$ error		Sample Size $\pm 5\%$ error		Sample Size $\pm 3\%$ error	
		Split 50/50	Split 80/20	Split 50/50	Split 80/20	Split 50/50	Split 80/20
Canada	3460	94	61	346	230	816	571
United States	14193	96	62	375	242	993	652

A 50/50 split is traditionally used as it represents the most conservative value (Vaske, 2008).

Whereas an 80/20 split indicates that the population answers are less variable. Therefore, the researcher constructed a sample size following a confidence level or a certainty of 95% with a 50/50 split in order to reach a conservative split, yet a sufficient sample size. Table 3.2 shows the constructed sample frames used in this study and their calculated sample sizes against the actual number of questionnaires that were sent.

Table 3.2: Web-based survey calculated sample sizes against the actual samples sent

Participants Recruitment	Sample frame	Sample size $\pm 5\%$ Confidence Interval	Sample frame	Sample size $\pm 5\%$ Confidence Interval
	Canadian Architects		American Architects	
Web-based Survey	3460	346	14193	375
Actual number sent	390		630	

The survey was administered from June to September 2013. Email invitations were sent to sampled respondents with a link to the web survey. To enhance the survey response rate the researcher followed these strategies:

- The researcher personalized each respondent's emailed survey in order not to be viewed as junk email or part of mass marketing emails (Vaske, 2008).
- The researcher used follow up emails or survey reminders as a tool to remind respondents of the importance of this study and the value of their input (Dillman et al., 2009).
- A strategy to use 3 email reminders was adopted, with a time interval of 4-5 days between each reminder.
- The researcher indicated that the survey would take approximately 10 minutes to complete, with the aim of encouraging architects to respond.
- The researcher considered the timing of architects' work schedule when sending the survey. For example, Monday morning was avoided as it is usually a time to catch up with different unfinished tasks from the previous week.

3.4.2 Interviews

The first category of interviewees was short-listed utilizing the web-based survey. In order for the researcher to schedule a convenient time for their interviews, respondents were asked -in the survey- to provide their email addresses, if they wished to further discuss their experiences.

From Canada, a total of nine (9) architects indicated their interest in participating; however, after the researcher contacted them to schedule the interviews, only three (3) architects confirmed their willingness to participate. One of the three interviewee architects referred the researcher to an engineer who worked closely with the architect on a BAPV project. The researcher was able

to conduct an interview with the engineer to supplement the architect's story and experience.

Therefore, a total of three architects and 1 engineer were interviewed.

From the United States, a total of three (3) architects expressed their interest in participating. The researcher made multiple efforts to establish contacts with the potential participants and schedule interviews; unfortunately, all efforts failed and none of the three architects were interviewed.

Prospective interviewees were all contacted via email to schedule an appropriate time for the interview. Interviews were conducted during the months of July to November, 2013. All interviews were conducted over the phone and were audio-recorded with participants' consent. The researcher verbally provided the research objectives along with the consent at the beginning of the interview as suggested by the Office of Research Ethics (ORE).

Key informants were recruited following a non-probability purposive sampling technique with the intent of obtaining the perspective of a very significant group of the solar industry. Patton (2002) states "The logic and power of purposeful sampling derive from the emphasis on in-depth understanding" (p. 46). The researcher made initial contact via email, followed by a phone call in the cases where no response was received. The initial email contained information about the study's objectives along with a request to participate in a phone interview. Interview times were scheduled using follow up emails. All interviews were conducted over the phone and lasted between 15-30 minutes on average. A total of nine (9) key informants, architects and engineer interviews were conducted for this study. All interviews were audio-recorded after the researcher obtained interviewees' verbal consent.

Table 3.3 illustrates the total number of short-listed architects contacted and the actual number interviewed. It also shows the total number of key informants contacted and the actual number of key informants interviewed from both Canada and the U.S.

Table 3.3: The number of potential architects and key informants contacted versus the actual number interviewed

	Potential Participant	Actual Participant	Potential Participant	Actual Participant
Country	Canada		United States	
Short-listed Architects	9	4 (3 architects+1 engineer)	3	0
Key Informants	4	3	2	2
Total	13	7	5	2

3.5 Data Analysis Methods

Due to the nature of this study, containing both quantitative and qualitative data, two data analysis strategies were used. The data analysis procedure for the web-based questionnaire was straightforward as the survey software automatically coded and calculated the frequencies of responses for the majority of the survey questions and presented them in tables and charts. To protect respondents' anonymity, the web-based survey software was set up not to collect any identifiers such as name or email or IP address. The researcher exported the raw data to Microsoft Excel for further analysis. Each respondent was given a unique code (such as CR, CR2...CR62). For example, the raw data were utilized to create Tables B-1 and B-2 (see Appendix B) which list responses per geographical location by means of counting the frequencies of reported provinces/states. In the cases where questions allowed elaboration or comments on certain topics, the textual data were presented per question (where applicable) to inform the reader of respondents' perspectives.

The majority of the survey questions required a single one-way table that delivered the basic information, such as the number of respondents who selected choice A or choice B. Cross tabulation or a two-way table was used once to provide a profile of early and late respondents and ease the interpretation and comparison between the two groups of respondents (See Section 4.2.3). It is important to mention that survey questions were designed and analyzed to answer the research questions established earlier in this study. For example, the first portion of the survey questionnaire was designed to measure the level of awareness about BIPV/BAPV technology, and the source of their education (See Appendix A). Due to the low response rate, the quantitative data results are to be interpreted as exploratory in nature rather than statistically significant.

The second part of the data analysis process contains the qualitative data collected from interviews. Each interview was recorded using voice recorder software saved on an external hard drive (protected with a password) and transcribed within 2-3 weeks of the interview date utilizing Microsoft Word. Transcribing interviews was meant to help the researcher get familiar with respondent perspectives and accordingly helped in constructing themes or concepts. It is essential to study all interview details, yet not to miss the broad view of the research objectives (Chenail, 2012). Interviews were transcribed for core discussions to ensure accuracy; however, introductory and concluding statements, participants' background information or identifiers were not transcribed. In some cases, where a word or two were not clear due to the quality of the recordings, which is often pointed out by researchers as transcription errors, the researcher made an educated guess based on sentence context as well as what made sense in the whole interview context in order to fulfill the meaning rather than alter it (Poland, 1995).

Despite the availability of electronic data analysis tools, the researcher decided that a manual analysis was appropriate since the number of interviews conducted was not large. For qualitative research, coding is an important tool to organize and analyze textual data. Basit (2003) explains that “What coding does, above all, is to allow the researcher to communicate and connect with the data to facilitate the comprehension of the emerging phenomena and to generate theory grounded in the data” (p.152).

The initial step in coding the data is to get familiar with each interview’s major themes. For this study, themes such as the feasibility of BIPV/BAPV products, the connection to the grid process, electrical performance of systems and the availability of financial incentives were constructed. In order for the researcher to construct a story out of the data to answer the research question, the themes and concepts were: a) given a detailed description; b) compared among interviews; and c) their interconnections were reported. Relevant quotations of significant importance were added to the results to give an actual feel of participants’ views (Dierckx de Casterlé, Gastmans, Bryon, & Denier, 2012).

3.6 Ethical Consideration

This study was granted the ethics clearance from the Office of Research Ethics (ORE), on June 6, 2013. Respondents were treated as per the University of Waterloo ethical guidelines. This study posed no risks to participants; their participation was voluntary and they were informed prior to participation that they could withdraw their consent at any time. No data were collected, analyzed or published without participants’ consent. Participants were informed prior to participation of this study’s goals, objectives and any potential outcomes. Confidentiality of participants was protected; their identity remains anonymous throughout.

3.7 Limitations

It is important to list the limitations encountered in this study, because some of those limitations had large effects on the survey response rate as well as the length of interviews.

- Research geographical scope: the scope of this study was large and required multiple methods of data collection. In addition, the constructed sample frames were relatively large.
- Access to information: the researcher attempted to obtain architects' membership lists from the responsible regulatory bodies. Since these attempts failed, two lists were constructed by the researcher utilizing the online membership directories for the AIA and RAIC.
- Support from participants: this study targets a group of the population that commonly has very busy schedules, so sharing their time to participate in this study was a large barrier that likely reduced the response rate.
- Quality of communication: due to interview participants being in two countries, it was practical to conduct interviews over the phone. The quality of medium was an issue, in some cases, specifically when participants were on a speaker phone.
- The ease of ignoring email invitations: since this study's respondents were contacted via email, the probability of ignoring the web survey invitations was high.
- Time management: this study was conducted in two phases; each phase of this study had its procedures and protocols that required preparation and scheduling.
- Non-response (selection) bias: the majority of respondents indicated awareness and interest in PV technology, yet few have employed BAPV/BIPV products within their projects (see Figure 4.9). It is possible that those architects lacking awareness, interest, or experience elected not to respond to the survey.

4 RESULTS

4.1 Introduction

This Chapter contains the results obtained from both the web-based survey questionnaire and the in depth interviews discussed earlier in Chapter 3. The purpose of administering the survey and conducting the interviews is to collect primary quantitative and qualitative data about architects' awareness of PV benefits and applications, interest in applying PV products within their new constructed or retrofitted projects, in addition to identifying any potential barriers that respondents believe that are slowing down the adoption of BIPV/BAPV technology.

Hennink et al.(2011, p.290) explains that in mixed method research, the data should be analyzed in a way that is appropriate to the method used to collect them; therefore, it can be challenging for researchers to decided how to present both qualitative and quantitative results in one study. Some of the strategies Hennink et al. suggest in such cases are:

- “Presenting the results by key topics or code”: for example, the cost of PV systems can be a key topic. Survey data that are related to PV systems' cost can be reported along with any contextual clarification obtained from interview participants.
- “Presenting the results by data collection method”: for example, the researcher presents survey data results first followed by interview findings.
- “Presenting the results by research objective”.

The researcher decided to follow the second suggestion above for this study; since this portrays the sequential design method explained in Chapter 3, and provides a comprehensive and organized flow of information to answer the research questions.

4.2 Web-Based Survey Results

4.2.1 Response Rate

Table 4.1 indicates the numbers of sent surveys and received responses in both Canada and the U.S; in addition, it shows the number of bounced email invitations, those who opted out and the total of subjects who never responded to the survey.

Table 4.1: Number of Sent, Received, Opted out and No-response Survey Questionnaires

	Sent	Received	Non-response	Bounced	Opted out
Canada	390	62	291	12	25
United States	630	40	556	5	29

In Canada, a total of 62 responses were received, which indicates a response rate of 16 %, as calculated:

Number of Completed Surveys/Number of Respondents Contacted*100% = Response Rate

[Received/ (Sent-Bounced)*100%= Response rate]

[62/ (390-12)* 100%= 16%]

In the U.S, out of the 630 invitations that were sent, 40 architects responded to the survey which indicates a response rate of 6% as calculated: [40/ (630-5)*100%= 6%]

Despite the fact that not all of the 40 American respondents or the 62 Canadian respondents fully completed every question of the survey, they were received as a sincere effort to answer the survey questions. However, after analyzing their responses, the researcher found out that 4 Canadian responses and 3 American responses were invalid; due to the fact that respondents had either not provided their consent to participate or had indicated their wish not to participate in the

study. All valid survey respondents were coded (see Table 4.2) to protect their identity and guarantee their anonymity.

Table 4.2: Survey respondent and interview participant assigned codes

Survey Questionnaire Respondents	Codes
Canadian respondents (CR)	(CR1,CR2,CR3.....CR62)
American respondents (AR)	(AR1,AR2,AR3.....AR40)
In-depth Interview Participants	Codes
Canadian participants 3 Architects 1 Engineer	CA1,CA2 and CA3 CE1
Canadian key informants CanSIA CanMET ENERGY City of Toronto	CI1 CI2 CI3
American key informants NREL ASES	AI1 AI2

4.2.2 Response Timeline

As mentioned in Section 3.4.1, a total of 390 questionnaires were sent to Canadian respondents, in addition to 630 survey questionnaires that were sent to American respondents. Figure 4.1 illustrates the weekly response timeline of a total of 62 responses received from sampled Canadian architects (16% response rate) and a total of 40 responses received from sampled American architects (6% response rate) between June 24th, 2013 and September 9th, 2013. The Figure indicates that the majority of Canadian responses ($\approx 56\%$) were received on the first week of the survey administration.

During the first four weeks 56 out of 62 responses were received ($\approx 90\%$), the rest of responses (6 responses or $\approx 10\%$) were scattered over the seven remaining weeks of the survey administration window. Whereas the responses' timeline for American architects indicates that during the first week of administering the survey, 15 out of 40 responses were received ($\approx 38\%$). It also shows that during the first four weeks of the administered survey 25 out of 40 responses were received ($\approx 63\%$), the rest of the responses were scattered over the seven remaining weeks of the survey.

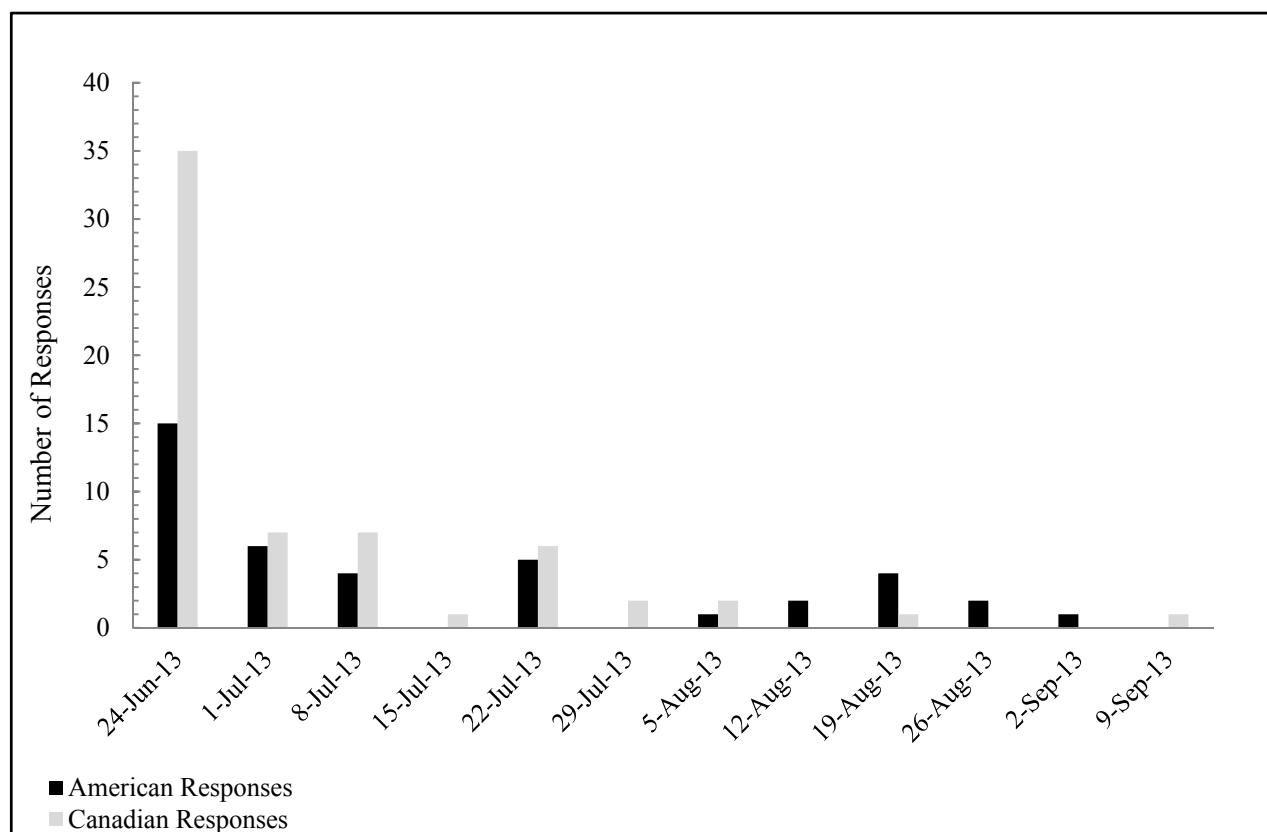


Figure 4.1: Response Timeline for Canadian and American Respondents

4.2.3 Respondents' Profile

To have a clear idea if respondents who participated in the survey were mostly architects who are environmentally aware and interested in BIPV/BAPV technology; the researcher compared the first wave of responses (the first two weeks of the survey administration as shown in Figure 4.1 of the responses' timeline) against the later responses. In Canada, two thirds of the responses (n=42) were received in the first two weeks and approximately half of American responses (n=21) were also received during this time period.

Table 4.3 shows the results of a comparison between the early and late respondents. The results indicate that there is no major difference in most of their responses with the exception of their practical experience employing PV; the first group of Canadian respondents had a higher percentage (43%) employing PV in their projects compared to the later wave of respondents (19%). The majority of respondents from both groups indicated that they are aware and interested in employing BIPV/BAPV products.

Table 4.3: Comparison of Responses between Early and Late Respondents

Comparison Criteria	Canada's Responses n=62		United States Responses n=40	
	Early Wave n=42	Late Wave n=20	Early Wave n=21	Late Wave n=19
Architectural Specialty	n=33	n=22	n=19	n=17
Institutional	70%	55%	53%	42%
Commercial	30%	45%	47%	58%
Aware of the technology	86% (n=32)	80% (n=18)	90% (n=20)	88% (n=16)
Aware of Financial support	11% (n=38)	6% (n=16)	39% (n=18)	41% (n=12)
Interest in employing BAPV/BAPV	n=29	n=16	n=17	n=12
Yes	67%	56%	70%	67%
Maybe	33%	44%	30%	33%
Employed BAPV/BAPV	n=38	n=16	n=17	n=12
Yes	34%	19%	47%	41%
No	66%	81%	53%	59%

4.2.4 Responses by Geographical Location

In Chapter 3, it was explained how architects were selected utilizing a uniform probability sampling technique (simple random). Each architect had an equal opportunity of being selected regardless of his/her specialty or geographical location. Figure 4.2 shows the geographical distribution of survey responses from both Canada (Yellow dots) and the U.S. (Orange dots).²

Figure 4.2 also shows that the majority of Canadian responses were received from south eastern and south western regions of Canada. For example, the multiple/overlapping dots shown on the map near Toronto, Vancouver, or Colorado indicate that more than one respondent lived in each location. The Figure also shows that in the United States, the majority of responses were received from the Northeast and West regions with a slight difference in the number of responses between the Midwest and South regions. These results will be further discussed in Section 4.2.3.2 (Questions 2 and 3).

² Overlapping/multiple dots indicate that multiple respondents lived in the same city/region.

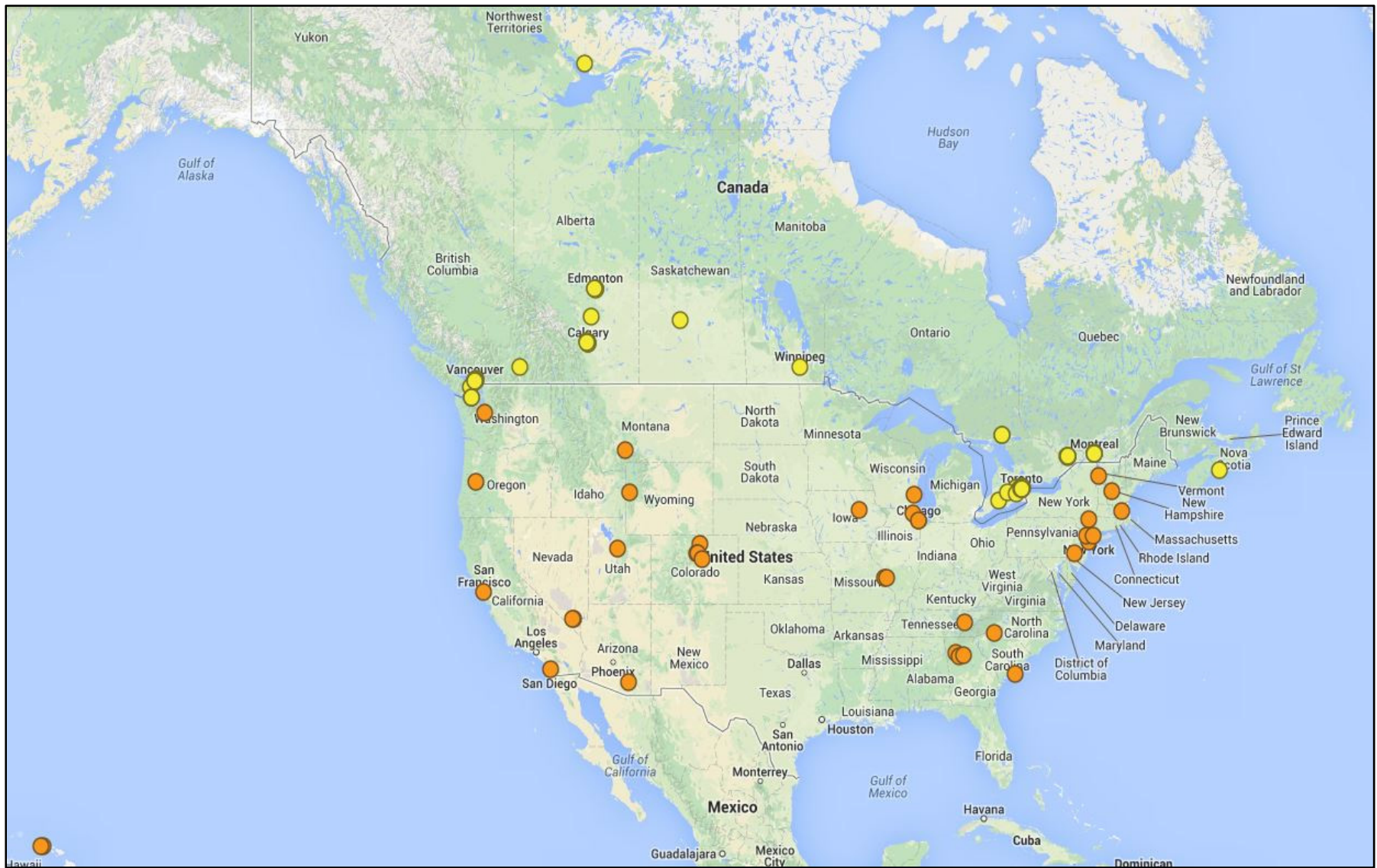


Figure 4.2: Geographical Distribution of Received Responses in both Canada and the U.S.

Source: Base map obtained from Google maps, 2013.

4.2.5 Survey Results

The web-based survey questionnaire consisted of three sections. The first section contained the study objectives along with the consent to participate form (See Appendix A). The second section contained a total of three questions regarding architects' background such as their country, their province/state of practice, and their specialties. The third section contained 12 questions that were designed to collect information about architects' awareness, interests and any potential barriers faced during the process of acquiring a BIPV/BAPV system. Listed below are the results for each survey question.

4.2.5.1 Section 1: Study Objectives and Consent Form

▪ Question 1: *Web Questionnaire Consent*

As noted above, the first section of the survey was dedicated to explain the study's objectives, along with the techniques used to protect respondents' anonymity (see Appendix A for the study's background and objectives). In order for the researcher to consider architects' responses valid, a consent form was signed electronically by the respondent choosing the box "I agree to participate in this study".

The results indicated that 94% of Canadian respondents consented to participate in this study; whereas 6% declined the request to participate. In addition, 93 % of American respondents indicated their willingness to participate in this study, whereas 7% declined the request to participate (Refer to Table B-3, Appendix B).

4.2.5.2 Section 2: Respondents' Background

- **Question 2, 3:** *“Select your country; select your province/state”.*

(Refer to Tables B-1 and B-2, Appendix B)

- **Canada**

The Canadian architects' constructed list (RAIC members) contained 3,460 potential respondents. Table B-1 (See Appendix B) shows the number of potential respondents per province, it also shows the number of questionnaires sent and responses received. Figure 4.3 indicates that the highest number of responses per province, which is 27 responses (47 % of the total in Canada), was received from the province of Ontario (ON). British Columbia (BC) comes next with 13 responses (22 %) followed by Alberta (AB) with 10 responses (17 %) and Quebec with 4 responses (7 %).

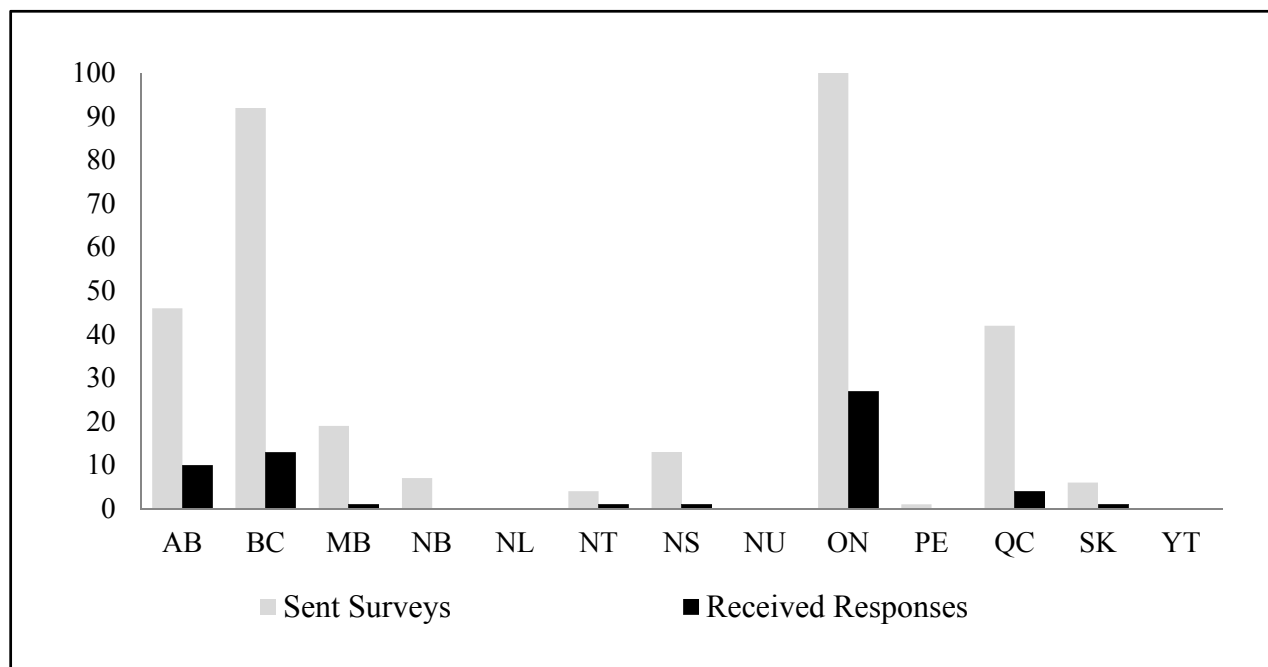


Figure 4.3: Distribution of Sent Surveys and Received Responses in Canada according to their Geographical Location.

▪ **United States of America**

The American Institute of Architects' (AIA) constructed list contained a total of 14,190 potential respondents. Table B-2 (See Appendix B) and Figure 4.4 show the number of survey questionnaires that were sent to potential respondents per U.S. regions and sub-regions; they also show the number of responses received, those who opted out and bounced invitations. The results indicate that the highest number of responses per U.S. region, 13 responses ($\approx 38\%$), was received from the West region. The Northeast region comes next with 9 responses ($\approx 25\%$). The remainder of responses were distributed equally (7 responses per region or 19%) between Midwest and South regions.

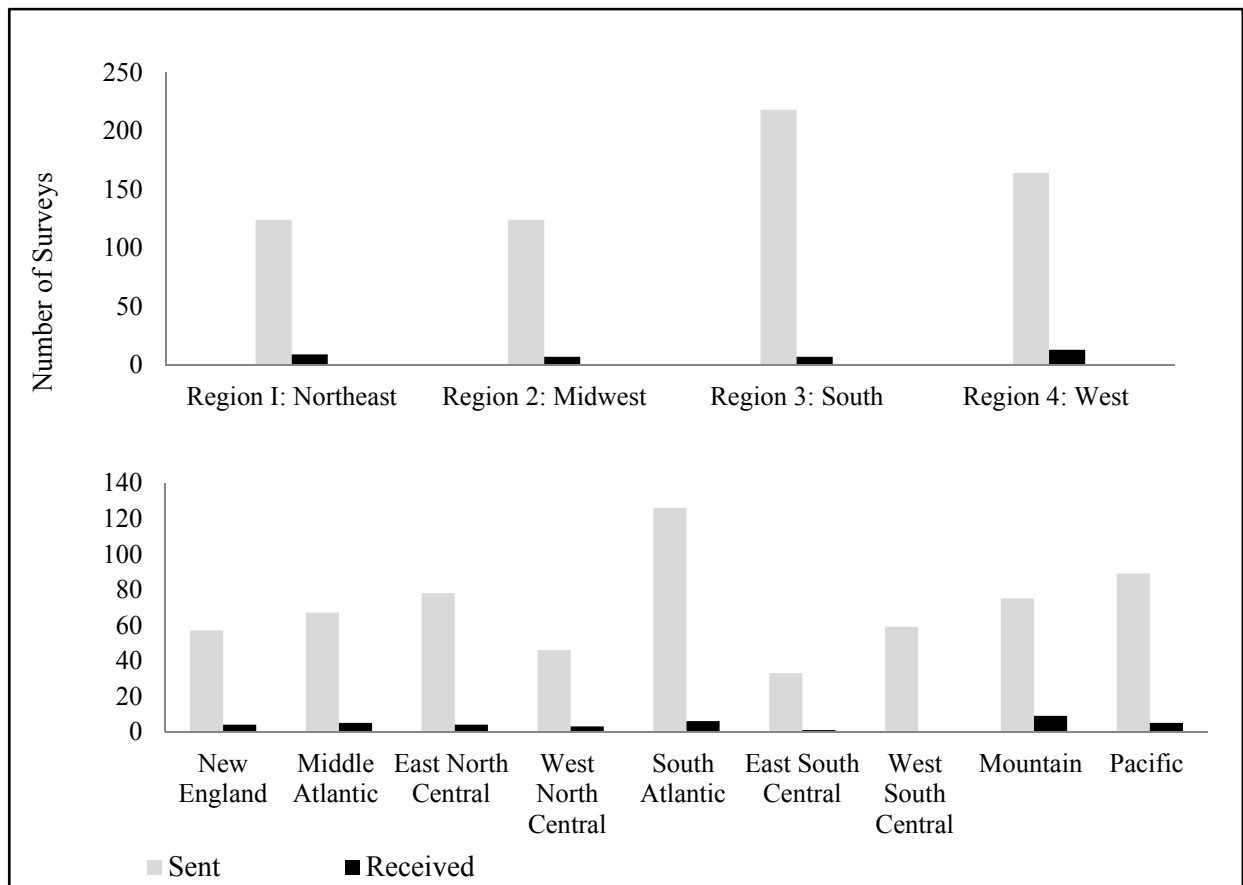


Figure 4.4: Survey Distribution by Geographical Regions & Sub-regions in the U.S. Regions obtained from (U.S. Department of Commerce Economics & U.S. Census Bureau, 2010)

▪ **Question 4:** “*Select your speciality*”.

Responses to this question are presented in Figure 4.5. The results illustrate that the majority of Canadian respondents ($\approx 75\%$) who answered this question specialize in institutional projects, followed by commercial ones (46%); whereas the majority of American respondents who answered this question (56%) specialize in commercial projects followed by institutional ones (50%). It is worth mentioning that many architects often have multiple architectural specialties.

Other specialties reported by Canadian and American respondents are: hospitality (CR85), heritage (CR13 & AR6), transportation (CR37, CR40), industrial (CR3), restoration (AR4) and attractions (AR30). (Refer to Table B-4, Appendix B)

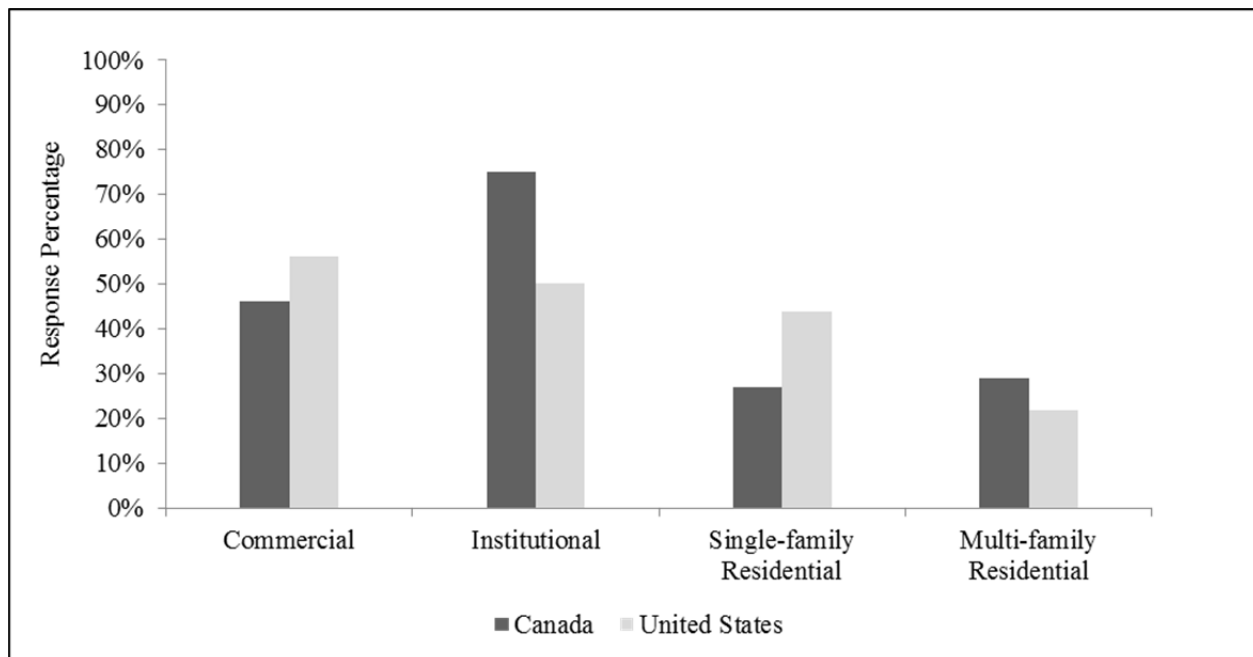


Figure 4.5: Canadian and American Respondents’ Architectural Specialties

4.2.5.3 Section 3: Respondents' Awareness, Interest and Perceived Barrier.

- **Question 5:** “Are you aware of Building Integrated/Applied Photovoltaic (BIPV/BAPV) Technology?”

Respondents' answers to this question are illustrated in Figure 4.6.

54 out of 62 Canadian respondents and 36 out of 40 Americans answered this question. The results show that 87% of Canadian respondents are aware of the technology; whereas 13% are not. Results also indicate that 89% of American respondents are aware of BIPV/BAPV technology; whereas 11% indicated their lack of awareness of the technology. (Refer to Table B-5, Appendix B)

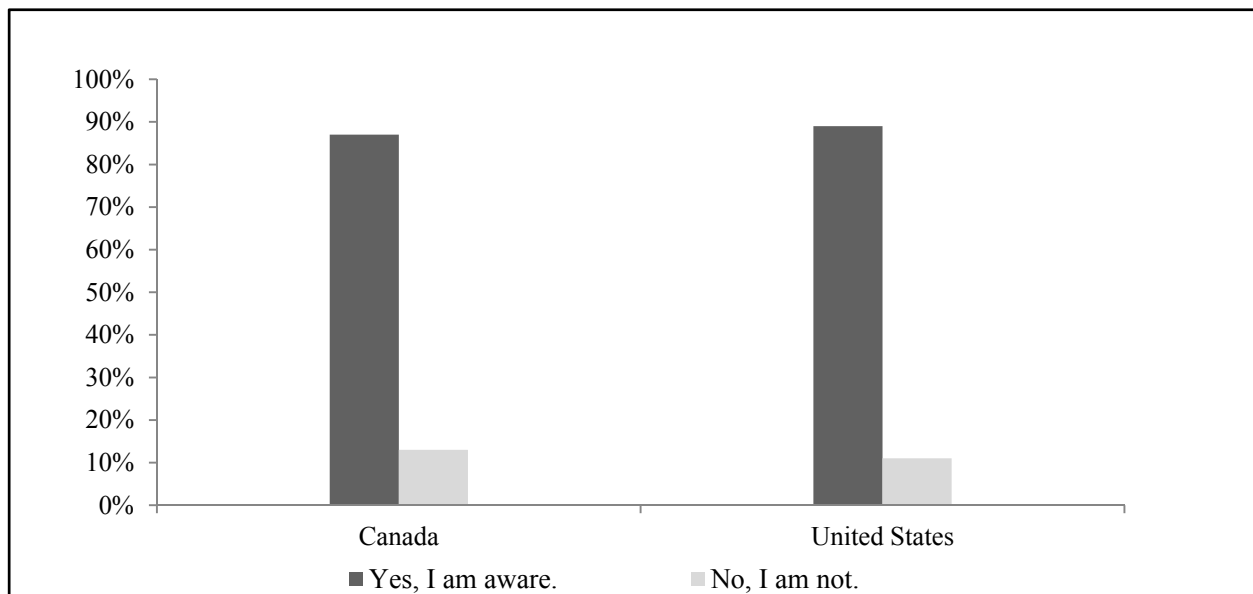


Figure 4.6: Respondents' Awareness of BIPV/BAPV Technology

- **Question 6:** “If your answer was Yes to Q5, how did you hear about (BIPV/BAPV) Technology?”

Responses for Canadian and American architects are illustrated in Figure 4.7.

Forty out of 62 Canadian respondents and 26 out of 40 Americans answered this question.

Respondents were given the option to choose multiple responses for this question. Twenty eight Canadian respondents and 12 Americans provided multiple answers.

The results show the majority of respondents heard about BIPV/BAPV from reading architectural or environmental magazines ($\approx 60\%$ of Canadian respondents and 54% of American). Respondents also reported that TV and radio were not among the modes of communication that marketed BIPV/BAPV technology (Refer to Table B-6, Appendix B). Some respondents mentioned that they have heard about BIPV/BAPV technology via other modes of communication such as: conferences (CR8, CR19, and CR50), consultants (CR40), sales representatives (CR52), projects (CR15), individual experiences (CR17), AIA convention (AR31), ASES website (AR33), vendors/sales representatives (AR2), seminars (AR25) and individual research (AR15).

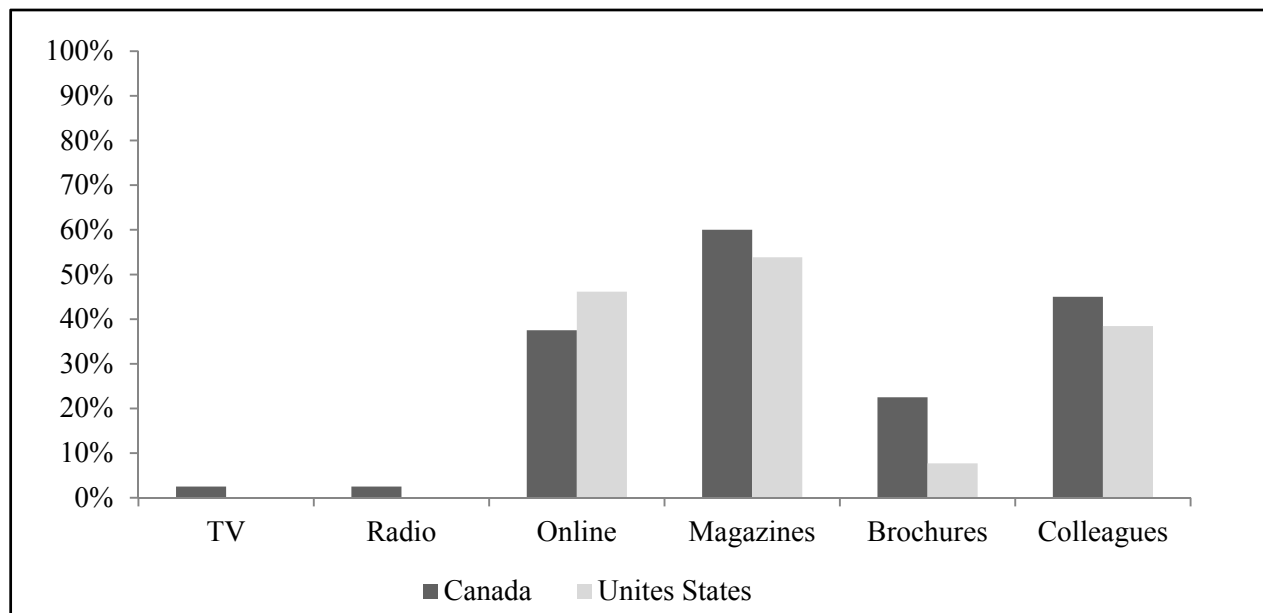


Figure 4.7: Respondents' Methods of BIPV/BAPV Awareness

- **Question 7:** *“Are you aware of any buildings (beside your project) that either Applied (Roof-Mounted) or Integrated Photovoltaic Technology?”*

Canadian and American respondents’ answers are illustrated in Figure 4.8. (Also refer to Table B-7, Appendix B). 55 out of 62 Canadian respondents and 36 out of 40 Americans answered this question.

The results indicate that the majority of respondents ($\approx 67\%$ Canadian and 64% American) are aware of projects that have either included a BAPV or BIPV component. Some respondents provided additional comments such as:

- *“There are a significant number across Canada”. (CR52, 2013)*
- *“Several buildings in Markham through PowerStream incentive”. (CR34, 2013)*
- *“Greenstone Government of Canada Building, Yellowknife”. (CR42&CR13, 2013)*
- *“Many of our projects include BIPV installations”.(CR48, 2013)*
- *“The newly built Library in University of Calgary”.(CR18, 2013)*
- *“Region of Waterloo EMS headquarters”.(CR17, 2013)*
- *“California Academy of Sciences”. (AR4, 2013)*
- *“Knoxville Convention Center / Tennessee Valley Unitarian Church”. (AR32, 2013)*
- *“PV integrated sun roofs over auto drop off areas and bus stops”. (AR14, 2013)*
- *“Denver International Airport (DIA)”.(AR10, 2013)*
- *“I subscribe to Environmental Building News and am a member of the American solar Energy Society, the Rocky Mountain Institute and USGBC so I've seen many projects in print”.(AR20, 2013)*

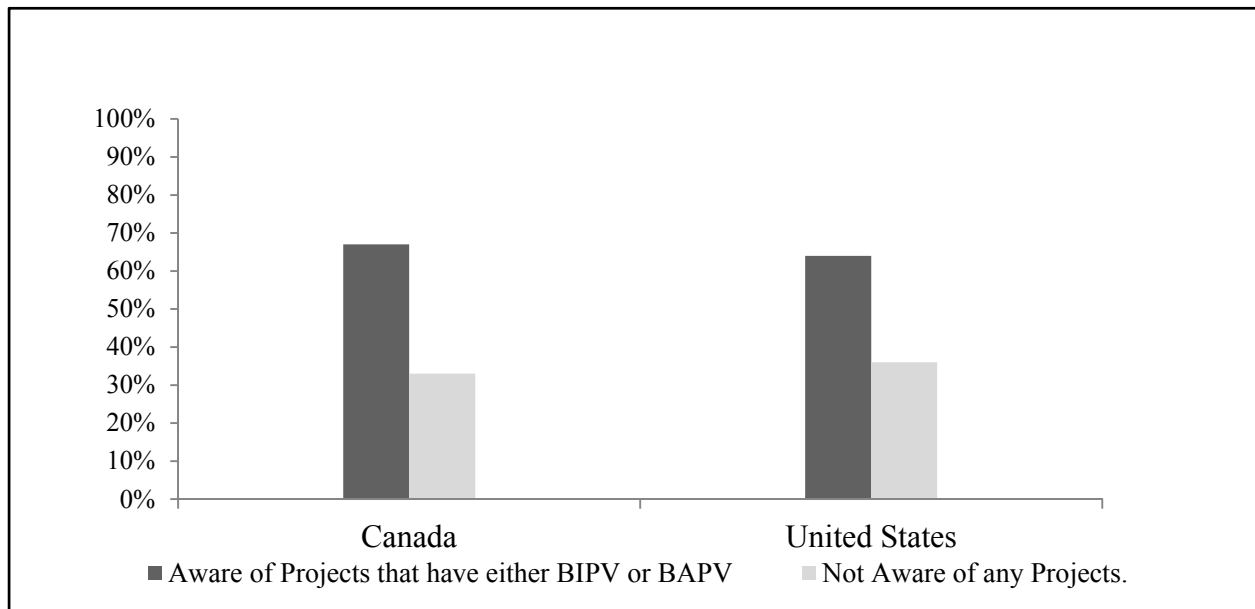


Figure 4.8: Respondents’ Awareness of Projects Other Than Their Own That Have BIPV/BAPV

- **Question 8:** “Have you either employed Applied Photovoltaic (BAPV-Roof-Mounted), or Integrated Photovoltaic (BIPV) in any of your projects?”

Canadian and American architects were asked if they employed either BIPV or BAPV to get a perspective about their practical knowledge of the technology and their individual experiences.

This question was also utilized to short-list respondents who have had the experience of employing PV within their designs. Short-listed respondents were asked afterwards to share their experience by participating in a follow-up interview. Approximately two thirds (69%) of Canadian respondents indicated that they have never employed PV technology. Canadian and American respondents’ answers to this question are illustrated in Figure 4.9. (Also see Table B-8, Appendix B)

In regards to American respondents, a total of 13 architects (43%) indicated that they have employed BAPV/BIPV within their buildings. Over half of American respondents (57%)

indicated that they have never employed PV. Some respondents elaborated on their answers by providing the locations of the projects they designed/supervised. Their answers are quoted below:

- “Red River College, Princess St. Winnipeg, Shandong Architectural University, Jinan, China, Promega daVinci Bldg., Madison WI (under construction) and others”. (CR19, 2013)
- “UTSC Instructional Centre, McMaster Innovation Park, CANMET Lab”.(CR6, 2013)
- “Walden Public School, Sudbury, ON”. (CR32, 2013)
- “Proposed for various regions of Waterloo Buildings and Milton Sports Centre”. (CR17, 2013)
- “A number of projects in the London region”.(CR48, 2013)
- “Schlitz Audubon Nature Center, Bayside, WI”. (AR23, 2013)
- “Desert Living Center and Springs Preserve Las Vegas, NV”. (AR8, 2013)
- “Kingsport, TN / Knoxville, TN”.(AR32, 2013)
- “San Bruno and San Diego, CA”. (AR5& AR36, 2013)
- “BIPV parking canopies, HI”.(AR14, 2013)

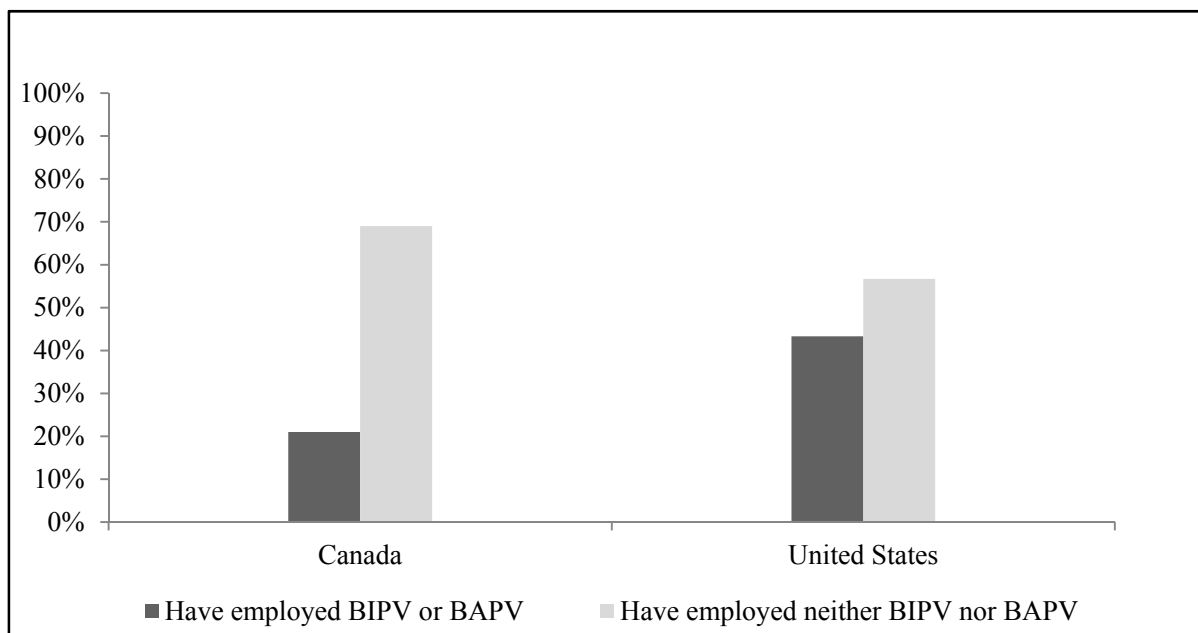


Figure 4.9: Respondents’ Answers to Question 8: “Have you either employed Applied Photovoltaic (BAPV-Roof-Mounted), or Integrated Photovoltaic (BIPV) in any of your projects?”

▪ **Question 9:** “If you have employed BAPV, what building component?”

Canadian and American respondents’ answers are illustrated in Figure 4.10.

Respondents were given the choice to select multiple answers for this question. 16 out of 62 Canadian respondents and 12 out of 40 Americans answered this question. 5 Canadian and 2 American respondents provided multiple answers.

The results show that the majority of respondents, approximately 94% of Canadian respondents and 83% of American respondents, who answered this question, indicated that they have employed a roof-mounted PV product (Also refer to Table B-9, Appendix B). The results also indicate that respondents had the least experience in applying PV products as siding/cladding material compared to their experience in applying PV products on roofs.

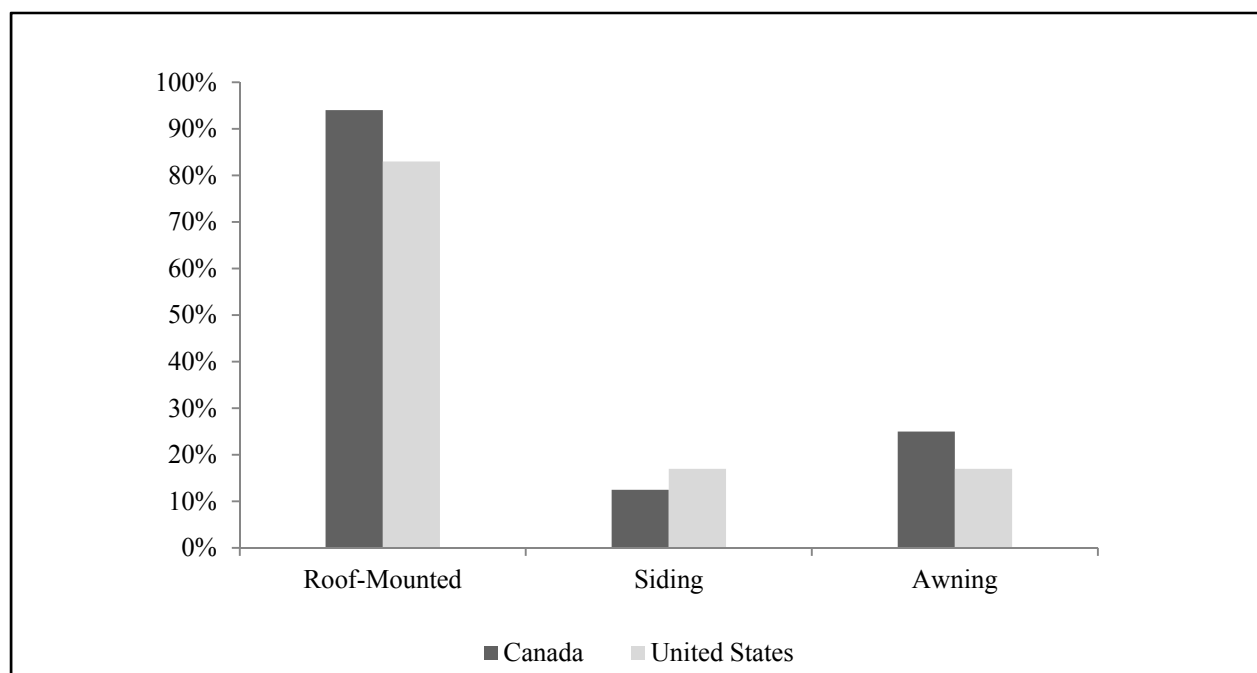


Figure 4.10: Respondents’ Answers to Question 9: “If you have employed BAPV, what building component?”

▪ **Question 10:** “If you have employed BIPV, what building component?”

Respondents were asked to select the building components that they replaced with BIPV. 12 Canadian respondents and 8 American answered this question. Respondents were given the option to select one or multiple answers. 3 Canadian and one American respondent provided multiple answers. The results indicate that 50% of Canadian respondents and 88% of Americans selected BIPV as a roof-integrated component.

Canadian and American respondents’ answers are illustrated in Figure 4.11 (Also refer to Table B-10, Appendix B).

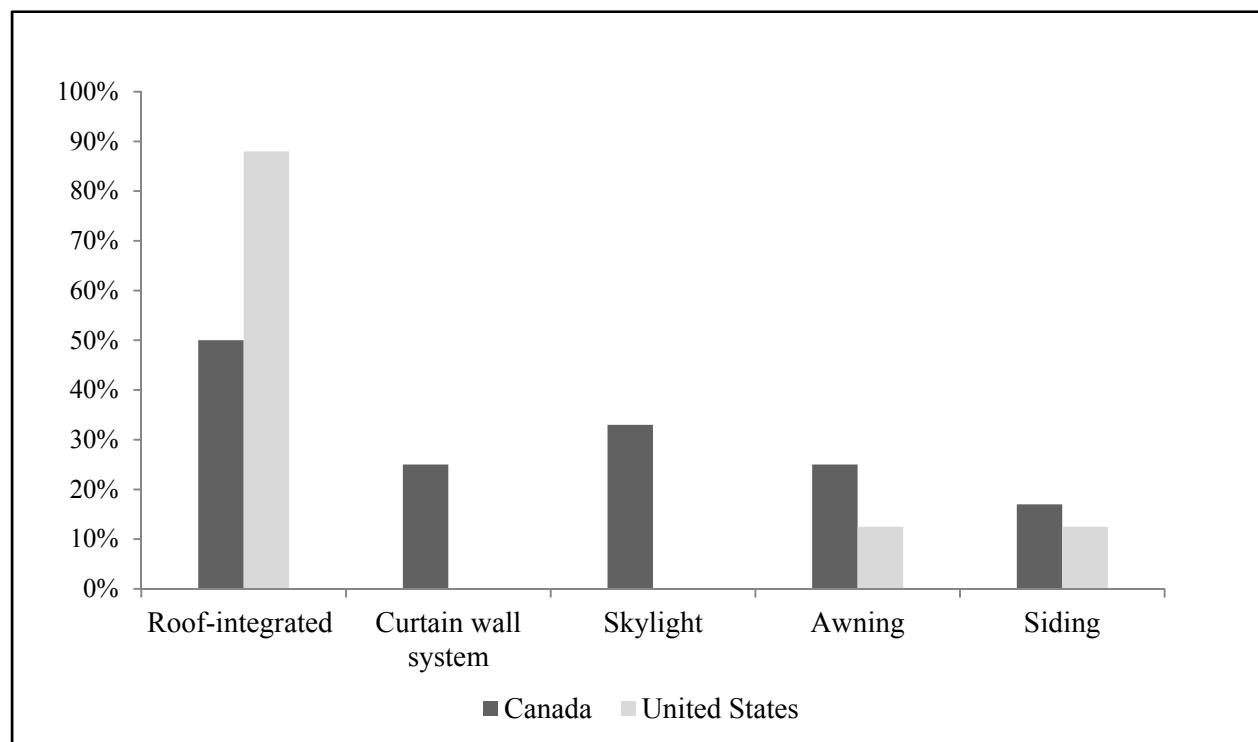


Figure 4.11: Respondents’ Answers to Question 10: “If you have employed BIPV, what building component?”

- **Question 11:** “If you employed either BAPV or BIPV in any of your projects, would you be interested in participating in an interview to further discuss it?”

As indicated in Section 3.4.2, the researcher utilized this survey question to recruit interview participants. A total of 31 out of 62 Canadian respondents answered this question. Initially, 9 respondents indicated their willingness to participate and have been contacted. A follow up email was sent to the potential participants to set up an appropriate time for the interviews. As explained in details in Chapter 3, three Canadian participants were interviewed.

As for American respondents, 20 out of 40 answered this question. Initially, 3 respondents indicated their willingness to participate in a follow-up interview. Multiple efforts were made to schedule an appropriate time for interviews; unfortunately, participants never responded. Results for both Canadian and American respondents are illustrated in Figure 4.12 (Also refer to TableB-11, Appendix B).

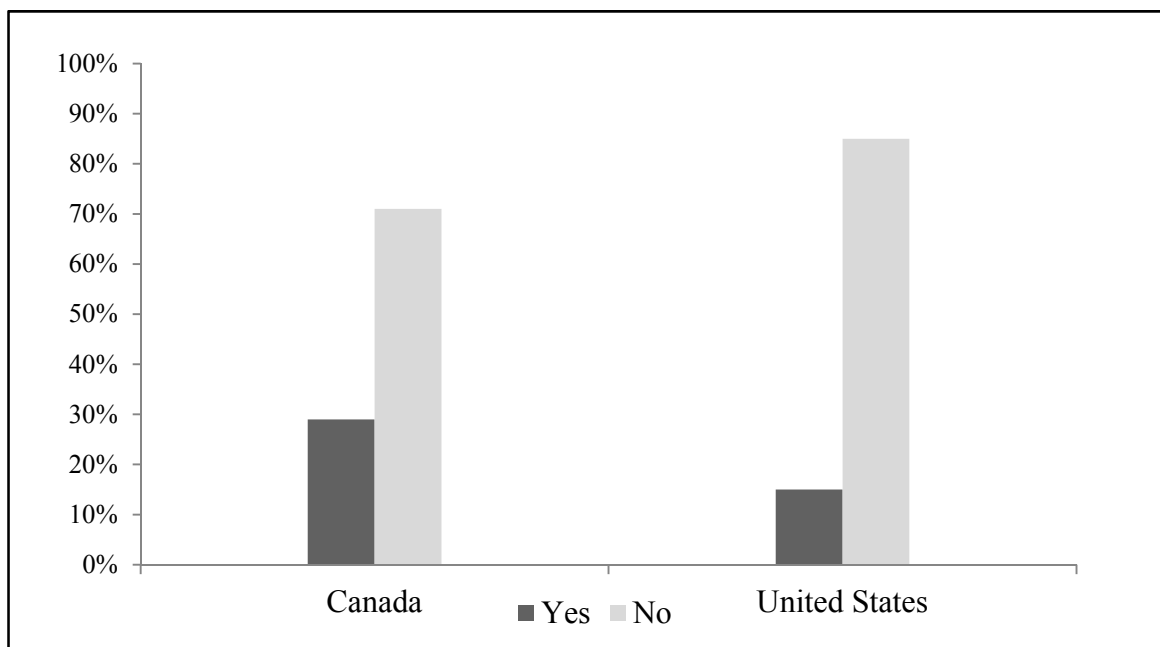


Figure 4.12: Respondents’ Answers to Question 11 “If you employed either BAPV or BIPV in any of your projects, would you be interested in participating in an interview to further discuss it?”

- **Question 12:** “If you have not employed either BAPV or BIPV in any of your projects, would you be interested in including them in your designs in the future?”

Respondents were asked about their interest in employing BIPV/BAPV systems in their future designs, whether they are new construction or retrofits. 45 out of 62 Canadian respondents and 29 out of 40 Americans answered this question. Respondents were given the choice to select multiple answers. 19 Canadian respondents and 14 Americans provided multiple answers. The results show that the majority of Canadian (64% new construction, 42% retrofit) and American respondents (69% new construction, 52% retrofit) are interested in employing BIPV/BAPV systems in their future designs. It is also noteworthy that none of the respondents indicated their disinterest in integrating or applying PV in their future buildings. The detailed results are illustrated in Figure 4.13 (Also refer to Table B-12, Appendix-B).

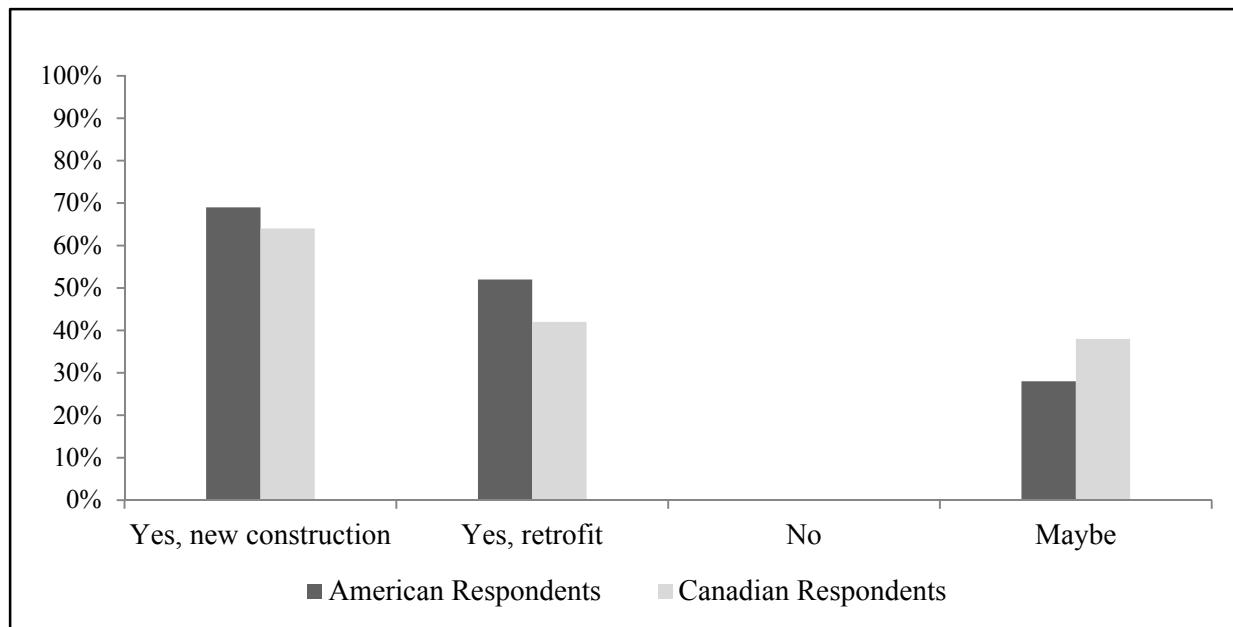


Figure 4.13: Respondents’ Answers to Q12 “If you have not employed either BAPV or BIPV in any of your projects, would you be interested in including them in your designs in the future?”

▪ **Question 13:** “Which building component would you most likely replace with BIPV?”

A total of 41 out of 62 Canadian respondents and 28 out of 40 American respondents answered this question. Respondents were given the chance to select multiple choices to answer this question. 31 Canadian and 19 Americans provided multiple answers.

Respondents’ preferences and interests further emphasize the vast range of opportunities that can be seized when PV is integrated within the building envelope. The results are illustrated in Figure 4.14. (Also see Table B-13, Appendix B).

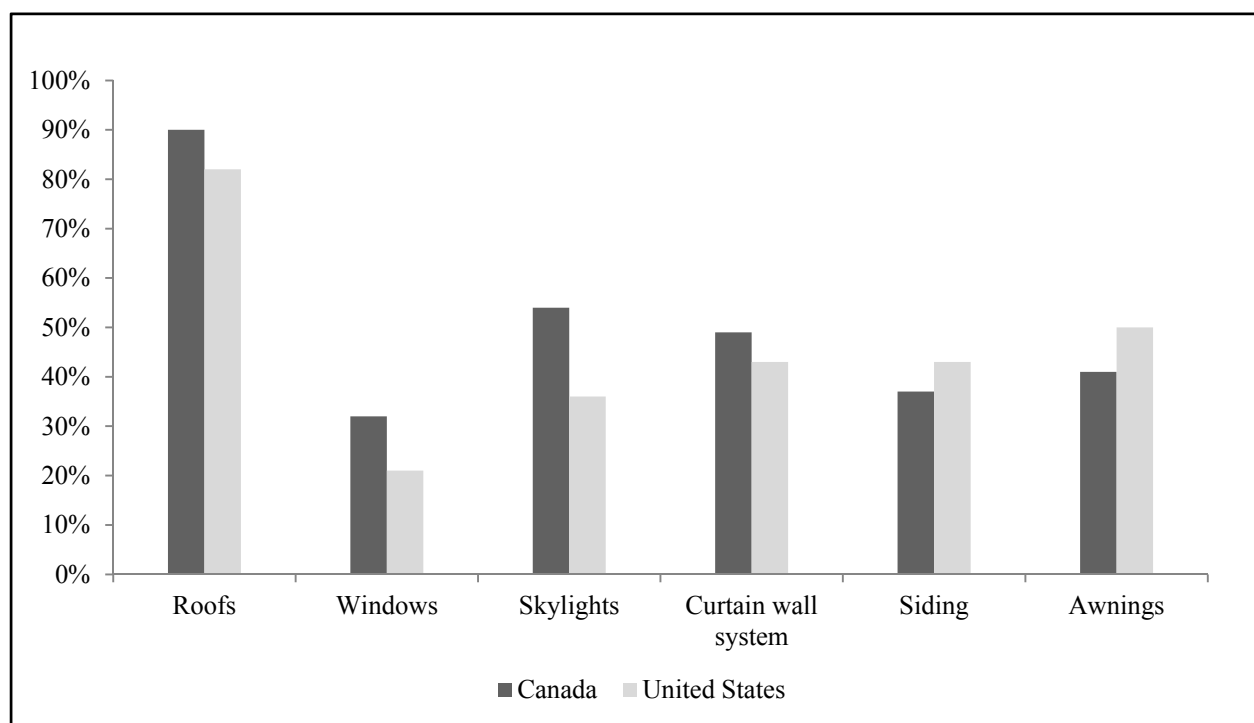


Figure 4.14: Respondents’ Answers to Question 13: “Which building component would you most likely replace with BIPV?”

- **Question 14:** “Are you aware of any government incentives or any other programs that encourage the deployment of BIPV/BAPV?”

Canadian and American respondents’ answers are illustrated in Figure 4.15 (See also Table B-14, Appendix B).

A total of 55 out of 62 Canadian and 30 out of 40 American respondents answered this question. The results show that the majority of Canadian and American respondents (approximately 89% for Canadian and 60% for Americans) are not aware of any government programs that encourage the adoption of BIPV/BAPV technology. Some respondents elaborated on their answers by providing additional comments or clarifications.

The additional comments provided about the financial incentive policies care quoted (displayed by level of government) in Table 4.4.

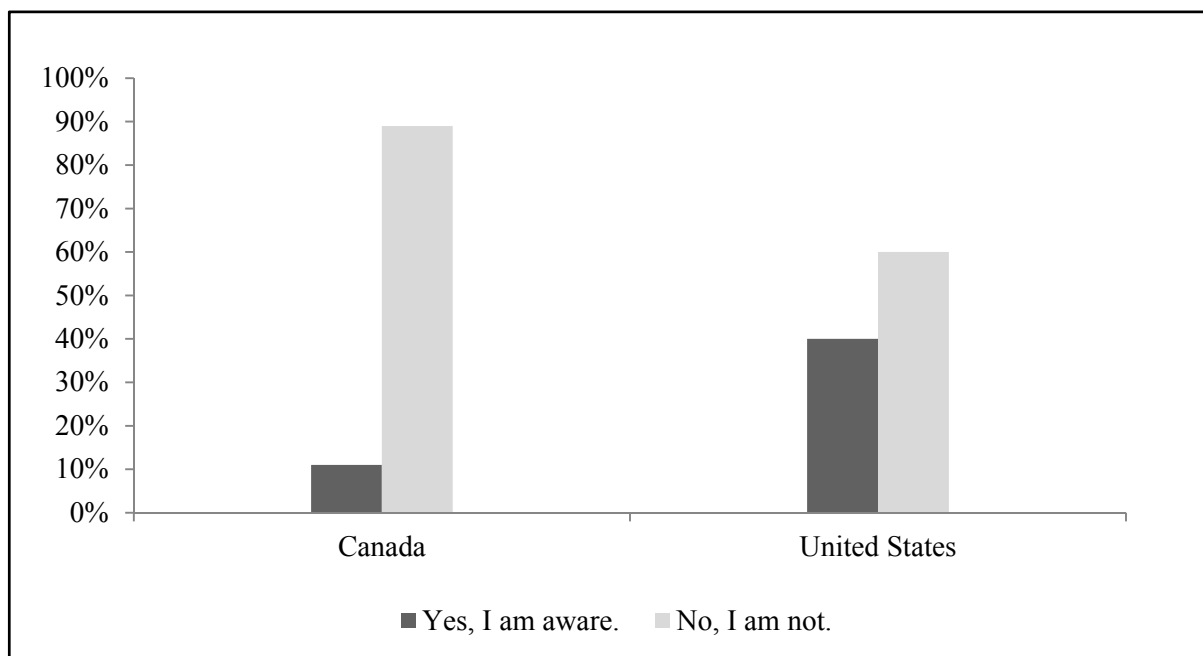


Figure 4.15: Respondents’ Answers to Question 14: “Are you aware of any government incentives or any other programs that encourage the deployment of BIPV/BAPV?”

Table 4.4: Financial Incentive Mechanisms Identified by Survey Respondents

Level of government	Canada	United States
Local	—	—
State/Provincial	“Feed-In Tariff (FIT) Program”. (CR6, CR17, CR48 & CR50, 2013) “Hydro-Quebec”. (CR37, 2013) “Green feed-in tariffs in some provinces and with some US utilities. Solar tax credits (US), some PV pilot programs in	“Renewable energy tax credits in Iowa”. (AR16, 2013) Energy Trust of Oregon has PV incentives”. (AR33, 2013) “Renewable Energy incentives by States, NJ and PA”. (AR17, 2013) “Vermont State Incentives”.(AR28,
Federal	—	“Federal energy tax credits / TVA”. (AR32, 2013)

▪ **Question 15:** “Rank BIPV/BAPV potential barriers according to their significance?”

As per Section 2.7, different potential barriers have been identified by scholars around the world that are responsible for altering the decision of adopting a PV system. Respondents were asked to rank different potential barriers according to their significance. A total of 51 out of 62 Canadian respondents answered this question.

The results indicate that the majority of Canadian respondents who answered the question ranked PV systems’ cost the most significant barrier followed by the existence of government financial incentive programs. Their responses are listed in (TableB-15, Appendix B) and are also illustrated in Figure 4.16.

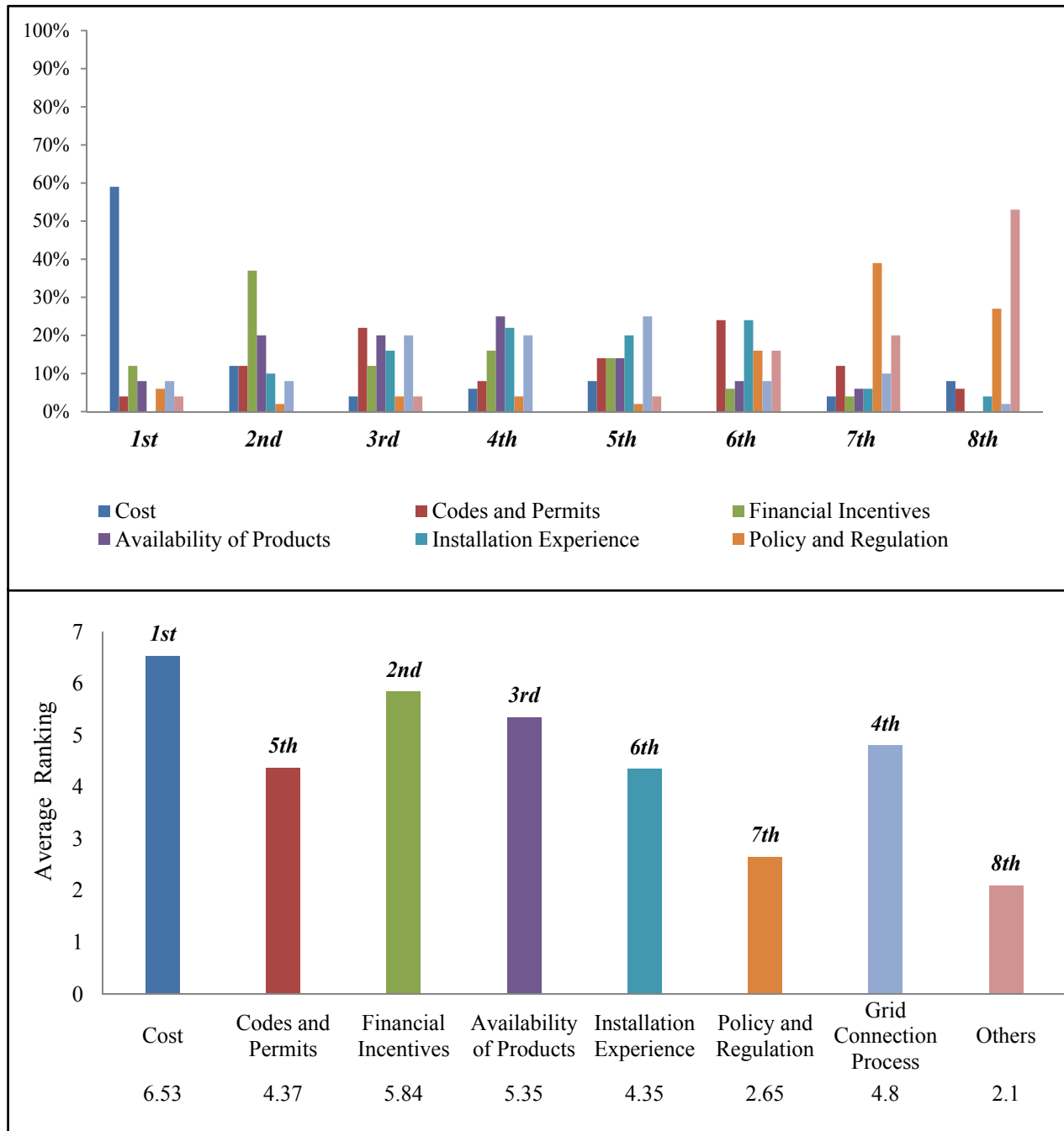


Figure 4.16: Canadian Respondents' Answers for Question 15: "Rank BIPV/BAPV potential barriers according to their significance?"

As for American respondents, 26 out of 40 answered this question. The results show that the majority of respondents indicated that PV cost is the most significant barrier, followed by the availability of products and codes and permits. The results are listed in (Table B-16, Appendix B) and also illustrated in Figure 4.17.

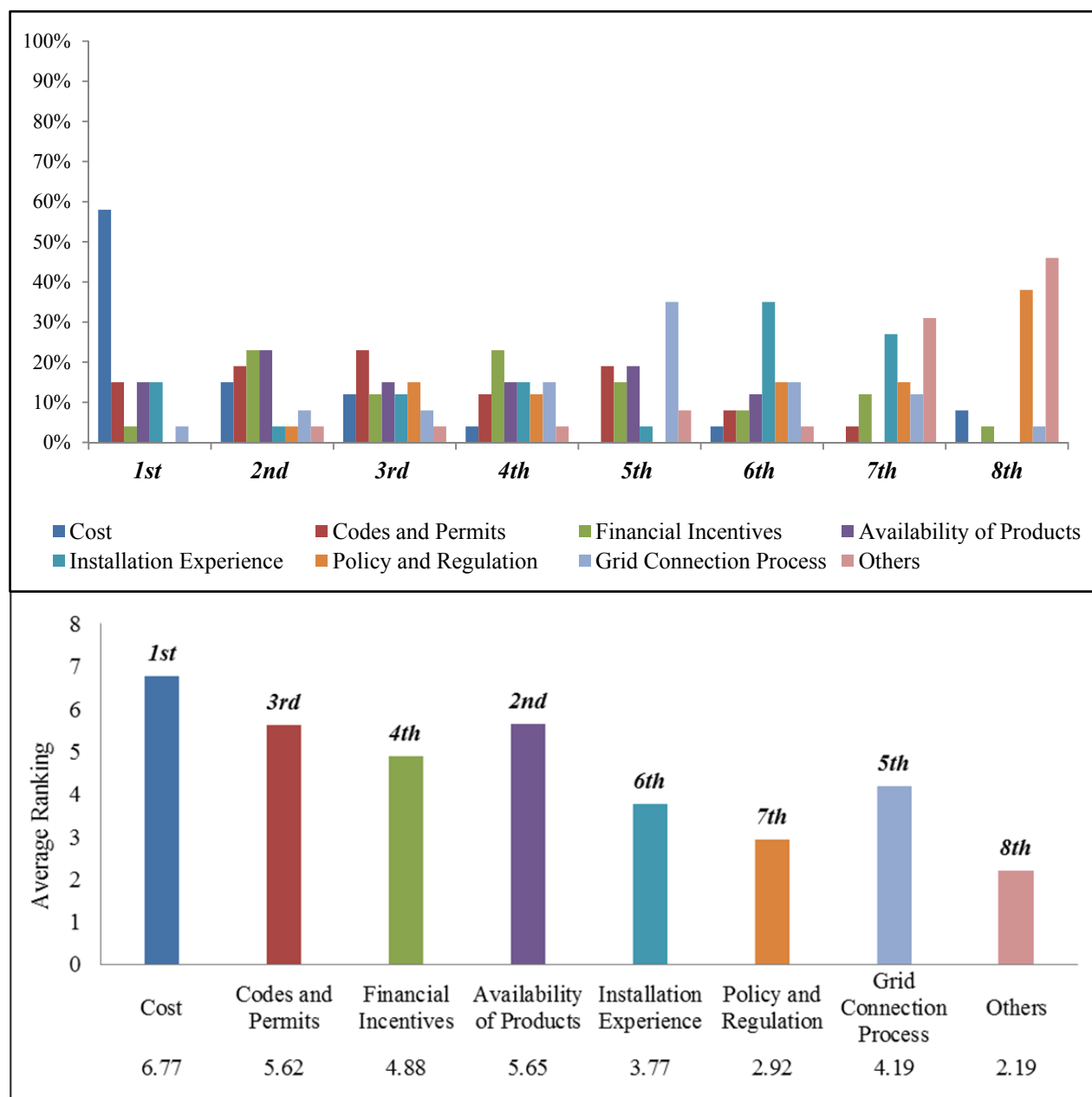


Figure 4.17: American Respondents' Answers to Question 15: "Rank BIPV/BAPV potential barriers according to their significance?"

▪ **Question 16:** “Do you think adopting BIPV is clients’ or designers’ decision?”

Respondents were requested to give their opinion about the power of decision-making when it comes to adopting PV systems in buildings. The reason behind asking this question is to acquire information about the power dynamics between clients and designers and how this relationship affects the clients’ awareness of PV technology and how it might affect their decisions.

A total of 46 out of 62 Canadian respondents and 22 out of 40 American respondents answered this question. Respondents were given the option to select multiple answers. 19 Canadian and 4 Americans provided multiple answers. The results are listed in (Table B-17, Appendix B) and are also illustrated in Figure 4.18.

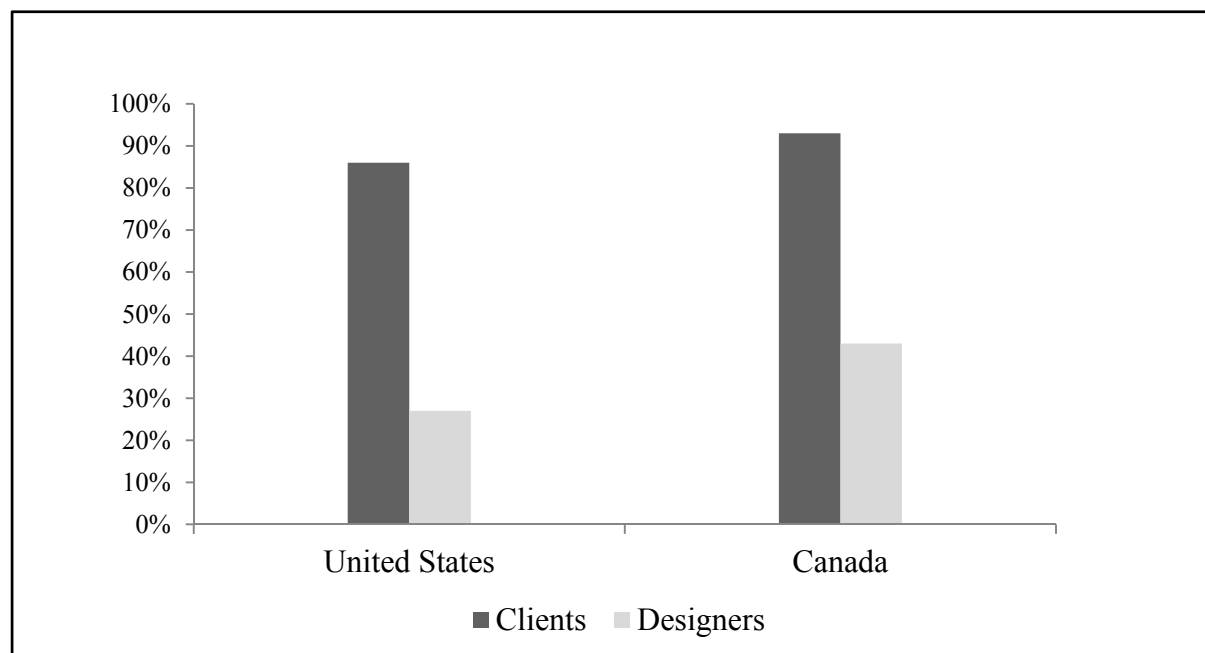


Figure 4.18: Respondents’ Answers to Question 16: “Do you think adopting BIPV is clients’ or designers’ decision?”

Some respondents provided additional comments such as:

- *“Depends on the project; either could be the lead interest “. (AR33, 2013)*
- *“He, who pays, says”. (AR4,2013)*
- *“Both clients and designers”. (AR31,AR25, AR21, AR23, AR16, AR3,CR56, CR1, CR52, CR51, 2013)*
- *“Designers need to present it as an idea, but clients have to pay for it”.(CR60)*
- *“Should be mandated by the government to force developers and builders to use these systems - it is criminal that the building boom in this country is proceeding without the use of these progressive and necessary technologies - left to their own devices, those out to make money in the building world will not change - it is long past due time to force these selfish people to be responsible and ethical”. (CR46, 2013)*
- *“Designers have to lead the way for Clients on this issue. Many Clients generally do not have the skills and abilities to see the issues here”. (CR32, 2013)*
- *“Designers can introduce and promote it. Until it is expedient and affordable in ordinary circumstances, it will be decided by clients- there are still a lot of headaches to overcome”.(CR19, 2013)*
- *“It's an integrated design decision for projects with a) a sustainable focus and b) appropriate budget and demonstrable payback”. (CR9, 2013)*
- *“All participants in an integrated design process”. (CR13, 2013)*
- *“Both, designer would propose but client must understand maintenance and other implications”.(CR51, 2013)*

4.3 Interview Findings

4.3.1 Introduction

This section summarizes the data collected from both short-listed respondents/architects and key informant interviews. As explained in Chapter 3, the researcher interviewed a total of three architects and one engineer from Canada, and findings from these interviews are summarized in Section 4.3.2. Furthermore, the researcher interviewed 3 Canadian and two American key informants, their interview findings are summarized in Section 4.3.3.

4.3.2 Participants'/ Architects' Interview Findings

As mentioned earlier, web-based survey respondents were requested to participate in a short follow-up interview to discuss in further detail their experiences and the lessons learned from deploying either BIPV or BAPV systems. This section summarizes the short-listed participants'/architects' interviews.

Bogdan & Biklin (1998) advised that before analyzing interview data, the researcher should get familiar with the content by reading the interview transcripts at least twice. Afterwards the researcher would be able to generate initial codes/themes which can be developed afterwards into more focused codes/themes.

Additionally, they emphasized that codes/themes should be established to address the research questions. However, they provided common types of codes/themes such as participants' setting or context, participants' perspectives and ways of thinking about a particular subject, processes or sequence of events, activities, events, methods and strategies (Bogdan & Biklin, 1998).

Accordingly, this study's interviews data are divided into major themes and sub-themes to better organize the information obtained and to ease its analysis and they are listed in Table 4.5:

Table 4.5: Participants' /Architects' Interview Themes

Interview Participants	Codes	
Canadian participants 3 Architects 1 Engineer	CA1,CA2 and CA3 CE1	
Research Inquiries	Theme/ process	Sub-theme
Architects' level of awareness	Project Initiation & Planning	Drivers and motives Design process
Architects' interest in deploying BIPV/BAPV products	Project Execution	The availability of BIPV/BAPV products The availability of experienced installers.
Barriers faced	Barriers	The connection to the grid process Road blocks faced during the execution/construction phase
	Lessons Learned	Lessons learned from the design and construction phase Client's/designer's satisfaction with the end result

4.3.2.1 Projects Initiation and Planning

▪ Drivers and Motives

Participants were asked about how the idea of integrating PV was initiated, and about the person/party responsible for suggesting the introduction of BAPV/BIPV products as clean energy generators and environmentally responsive elements of buildings design and operation.

They were also asked about the motives behind choosing this technology (see Appendix A).

Participants' answers are summarized below:

CA1 stated that he was involved in the design and supervision of a BIPV component in an institutional building in Quebec, as a demonstration project for a client that is eager to learn about environmentally-responsive technologies and test the performance characteristics of such technologies. He further stated that the motive behind integrating PV into the metal siding of the penthouse level was to demonstrate and validate both the design process of BIPV components and the technology of the system integrated in order to assess their economic feasibility and their technical performance.

It is noteworthy that the above-mentioned project is also LEED certified; however, CA1 stated that LEED certification was a separate issue, and the motive behind having a BIPV component was totally separate from the desire to achieve a LEED certified building.

CA2 described his experience in applying a BAPV system ($\approx 100\text{kW}$) on the top of an institutional building in Ontario (School). He emphasized that the client defined the requirement for this project, as much as the architect suggested it. He further stated that

“...the clients were focused on obtaining an energy efficient school environment. They consistently looked at every opportunity within their buildings to maximize efficiency and energy usage, it is their way of making the project as sustainable as possible, we have done a number of projects with this particular client and they have always been consistent”.

CA2 further explained that LEED certification or any other green labeling had never been his clients' drivers behind adopting PV systems for this particular project. He asserted that his clients did not buy into LEED metrics at all, because they did not see the value in using LEED metrics. He added:

“...they were fundamentally focused at energy and took their approach to energy above and beyond what LEED would technically acknowledge, and they did see the value in having lower energy costs every year from now till the end of the life of the building. That was what driving their projects”.

CA3 shared his experience in applying a PV system and explained that the motives behind that were:

“...to support the research that my client (an educational institution) is doing into renewable energy and therefore it has both the wind turbine and a number of different photovoltaic panels installed for research purposes. The second project was my client’s idea as part of looking at all the opportunities of improving the green performance of the building, and I think the timing of that project was such that aligned with that iteration of the FIT program; it was primarily the client’s interest and awareness of the fit program at the local municipality”.

CA3 further added that both of the projects mentioned above are green building certified.

However, he stated that building certification was not really the motivation behind applying BAPV systems; the motivation was primarily economic. His client found that PV was feasible considering the opportunity of making it part of the FIT program; therefore, it was predominantly economic.

▪ **Design Process**

Participants were asked if the design process was different in any aspects from the traditional design process due to the existence of an extra design feature (the BAPV/BIPV system).

Participants were also asked if they had faced any resistance from any member of the design team such as electrical and mechanical engineers. In addition, participants were asked about the reasons (if any) behind favouring BAPV over BIPV (where applicable).

CA1 explained that his client chose/favoured a BIPV system due to the fact that the system was a demonstration project of the technology and performance. He added that the architectural design team needed to have extra expertise from different disciplines to conduct a study prior to the architectural design to determine how the BIPV siding would be integrated. He further stated

that everybody from the integrated design team was on board and no objection or resistance was raised against the choice of the PV system or its location.

CA2 noted that the design process was fairly straight forward; however, the initial phase of the project included different stakeholders and various energy performance studies that are not usually done without the existence of a PV component. He emphasized that the initial goal was to achieve a net zero energy building. Therefore, the design process included extra costs of energy studies and the integration of different team players.

He further stated that

“...there were no real objections from the design team; we would have preferred if it was more of a building integrated rather than building applied, we thought there were opportunities to deal with solar shading that can be usually applied on the south facing glazing, integrate that with photovoltaics. But given the sequencing of the project and the sequencing of funding of the project that didn't come about, we were not able to make it happen, so we had to rely on enhancing our glazing to avoid any kind of excessive solar heat gain and deal with that piece rather than having an active shading component”.

CA3, on the other hand, stated that the design process was reasonably straight forward: once the decision was made to pursue the installation of a PV system, the client prepared a request for proposal to different PV system providers. Those providers were required afterwards to interact with the municipality and meet the requirement of the Ontario FIT program in terms of the application process and the documentation.

He further added that everybody across the board was in agreement of the system chosen;

however, how the PV system would be installed was debated and it was recommended that

“...rather than placing such a large system way up on a high roof like that by using a normally ballasted type of installation that we often see, we recommended to be directly connected to the roof structure, so it doesn't rely on any ballasted system. It is offset about 1.5 meters above the roof surface, so that facilitates access to the roof membrane so the roof can be replaced without altering the array”.

4.3.2.2 Projects Execution Barriers

Participants were asked if they had faced any barriers during the execution phase of their projects, such as the hardship of finding appropriate products for their designs, the availability of trained/experienced installers who are responsible for installing, operating and maintaining PV systems. In addition, they were asked if they had connected PV systems to the utility grid and if they had received any government financial incentives to subsidize the cost of the system.

CA1 indicated that the major barrier they faced was mainly the cost of the system; otherwise, the design and execution were smooth. He stated that they worked with a Toronto firm that provided them with customized (thin film) PV panels, and the system analysis and calculations.

Afterwards the project was turned over to the general contractors who built it according to the design preference and the details discussed earlier with the engineers.

He added that finding the desired PV product or an experienced contractor was not an issue at all. In addition, they did not have any conflict with the building codes, because he stated that

“...the system was architecturally fully integrated to the façade. All people would not tell they are photovoltaic panels; they have to know that ahead of time. This is to show that PV panels can be designed fully integrated and harmonized with the design of the rest of the building. That’s what we demonstrated”.

Furthermore, CA1 added that cost was the major barrier for this installation and this barrier was lessened when the project received a financial incentive (lump sum) from Hydro Quebec. He commented on his preference of choosing BIPV over BAPV system saying that

“...putting PV on the roof requires that you make special provision to support the system not to damage the roof and make an access to repair it, a lot of these things have to be resolved earlier in the process. The way we did it, we did not have such issues; the PV system was built into the wall, it was fully integrated and would perform like a wall, there was no real maintenance question as far as the building operation; however, there might be some maintenance questions in terms of the operation of photovoltaics”.

CA2 asserted that cost was a major barrier to acquiring a PV system. He stated that the client was trying to secure the funding to get the photovoltaics installed simultaneously with the building's construction; he added that

“...in this particular instance, the photovoltaic got applied to the roof of the building after the fact. It's more of a sequencing of the funding; it just took a longer time to secure all the funding related to the BAPV. In order to make them happen, the project actually was completed, occupied, I think it went through a year of use before the BAPV was put there”.

He further added that since the system was installed after the fact, it might be of value to speak to one of the electrical engineers (CE1) that was involved in the design of the system, because there was not much from the architectural side that they were involved in, apart from that front end planning. He commented that they did spend quite a bit of time and went through different option trying to balance the area available on the roof for the photovoltaics panels with the remaining roof area that could be utilized to install skylights in order to get some light to the depth of the building.

CE1 stated that everyone involved was interested in employing PV because of the financial gains. He added that the payback period stays the same with the Ontario FIT program for home owners to large building owners; however, when the engineers explain to the clients how FIT works and the all the paper work and documents required, interest dies off. CE1 further stated that the system performance, meeting the codes, the availability of products and finding trained/experienced installers are not issues at all. He elaborated that

“...there are many contractors, many installers; there is an abundance of resources out there in terms of installing equipment. Basically getting the solar panel on the roof and installing it and doing all the wiring that is not a problem; that happens just as quick as any project does. Everything that I can control (from the design and the overseeing of the contract) is almost seamless. That really works very well, lots of products out there, different application. The problem then become when you try to actually connect it to the grid. Unfortunately, by the time the installation was complete the Ontario FIT program was put on hold and everything was

being reviewed. So what we decided to do was connecting the system to the net metering program instead”.

CA3 stated that often cost is considered a major barrier when purchasing a PV system, since the panels themselves are still fairly expensive and hard to justify in the absence of an incentive program. However, in this particular project, the BAPV system was included in the design process early on, and the client was aware of the cost of the fully installed system. He added that finding experienced installers or PV products were not issues at all; however he stated that having a PV component

“...added a level of complexity for the contractor, the need to coordinate with other building trades the timing of installation of the PV array, the roofing and what is required electrically. I do not think there were any issues that were particularly difficult; it is just specially with such large installation it required a lot of effort on the part of the construction team, otherwise they would be involved in an ordinary community centre projects. Particularly the timing, to make sure that the roofing membrane is not damaged during the installation of the PV array, that took care and supervision on the part of the contractor, it just took a little bit of extra thinking and coordination compared to a normal project which have added an extra cost for the planning and coordination”. (CA3, 2013)

CA3 additionally commented that there was an issue of safety in meeting the codes. The municipality did have some concerns about the risk in the event of fire, and of a fire fighter going up on the roof (the risk of electrocution). However; the municipality and the design team worked together to resolve the issue by incorporating a switch that disconnects the grid from the system and enables fire-fighting without any electrical hazard (sic).

However, it should be mentioned , to clear CA3 point above, that disconnecting the PV system from the grid by installing a switch at the main power breaker does not halt the PV panel from producing electricity if they are still illuminated (Ontario Ministry of Labour, 2012).

4.3.2.3 Lessons Learned

Participants were asked about the lessons learned from their experiences in employing BIPV/BAPV in their projects. They were also asked about their satisfaction with the end result, there answers are summarized below:

CA1 commented that from his experience he found out that the engineering of projects that have BIPV component can be very delicate. There was a need to hire engineers that have specialized training in PV and the techniques for integrating it to the building. He stated that

“While you can replace metal panels or visual panels for Photovoltaics, the question is more of how to get economics going and getting designers to incorporate it from the beginning; I think if they start it at an early stage it can be a more normal process. We are fortunate it was a tall building when we started to consider it for the top of the building; the building was coming up from the ground”.

CA1 commented on his satisfaction with the end result by stating that he is very satisfied with the end result in terms of both aesthetic and performance. He added that the project was photographed and published in different magazines to show case the installation process and the final image. CA1 additionally stated that whether the project is a new construction or a retrofit, the idea is to take BIPV out from the experimental stage and get it into the acceptance stage. He claimed that architects and designers would incorporate BIPV if they do not feel that they are taking on more risk in terms of the performance of their building envelope.

CA2 looked at PV in a different perspective. He believes that PV should not be the goal itself; it is part of achieving sustainable projects. In other words, architects should start their designs by reducing the load required to operate the building before even applying any sustainable system to it. That is the first strategy; afterwards architects should seek options to provide renewable energy to the reduced or minimized load. He emphasized that

“Fundamental sustainable issues are just really good practice, they are part of the design process and part of being a good architect”.

CE1 summarized the lessons learned from his experience as an engineer by stating that

“Everything that I can control from the design and the overseeing of the contract is almost seamless. That really works very well, different kinds of PV products and different applications are out there, but it comes down to the red tapes. It is not very much that I feel I can do anything to push that through or make it a little faster”.

CA3 stated that from his experience, there is nothing about the PV system that the client or the design team is not happy with in terms of the end result of PV appearance and performance. He added that

“You do see the panels and we think that is nice, you do see the panels on the roof and it is a very contemporary looking building and the fact that you can see the panels on the roof stresses that they are a positive thing. Overall it worked pretty well, and also I know the performance of the panels in terms coming from the FIT program has also been as modeled and I know that the client has been happy from the electricity they produce”.

He further added that, from his experience, he learnt that if PV is to be integrated (rather than added) into the building materials and, in particular, the roof membrane, the overall benefit is going to be much more attractive to many clients. He emphasized that as long as architects are mounting elements on the roof, there will be issues with catching the wind and that might pose a limitation to PV adoption especially with the absence of an incentive program.

4.3.3 Key Informants' Interview Findings

As mentioned in Section 3.3.2.2, in order for the researcher to gain a comprehensive perspective, and triangulate the information obtained from interviewed architects about the various barriers responsible for slowing down the diffusion of BIPV/BAPV technology, different key informants

such as national research laboratories and solar industry associations were interviewed. Table 4.6 lists the interviewed key informants and the question they answered.

Table 4.6 : A list of the key informants interviewed and the research question they answered

Key Informants	Codes	Question Answered
Canadian key informants CanSIA CanMET ENERGY City of Toronto	CI1 CI2 CI3	What are the major barriers that might influence the decisions to adopt a BIPV/BAPV system?
American key informants NREL ASES	AI1 AI2	

The key informants were asked to describe PV adoption barriers in the built environment from their scientific background as well as their solar market experience (where applicable). They were also requested to comment on the diffusion of PV technology in Canada and the United States.

AI1 stated that his perspective is from the standpoint of the material science and the work necessary to produce more efficient, lower cost and more earth abundant photovoltaic cells. With that context, AI1 stated that

“The biggest barriers at a high level, actually involve not too much cost today but the resistance/reluctance of the utilities around the world to allow more renewables in general and more photovoltaics ,in particular, onto their system. I would say that this is really one of the big challenges we currently face as a global community interested in zero carbon energy”.

He also added that people in developed countries/cities expect their electricity to always be on. However, one of the problems with renewables is that –for example- if the sun is not shining (if a cloud comes over) a large photovoltaic array is not producing electricity and that creates an intermittency problem that is a root challenge for utilities with the current business model.

However, at the level of an architect or a developer, AI1 believes that other problems are faced that are economic such as the cost of installing the system or practical such as the availability of trained affordable installers. Further he stated that

“...silicon PV, which is by far the largest market share, the actual cost of panels have dropped really perceptibly over the last 2-4 years, but what has not dropped in the U.S and Canada are the cost of installing the system, the cost of getting the permit necessary to actually connect it to the grid, these are what you call the soft costs. So the cost of everything beyond the panels and the inverter, these are the big barriers”.

AI1 commented on the diffusion of PV innovation saying that it is quite diverse from one country to another. Further, he added that

“The world leader in deploying PV is Germany, so you can go almost anywhere in Germany but certainly to the south of Germany, you can find the lowest PV installation cost in the world. Their installers have become highly skilled; they have developed very good practice for installing PV panels in both residential and commercial rooftops. That is actually a kind of a shining star, and most communities in Germany -by law- has been required to streamline/simplify the permitting process; however, that is not true for other European countries. Italy, for example, which has one of the highest retail electricity prices in Europe, is still a bureaucratic nightmare in terms of getting a PV system approved. It is highly variable. In the United States, the one real price up is California. California has a very vibrant PV market today, so if I were an architect I will have multiple options for how to design a building with PV, because I am in a community, generally, where PV is becoming almost the norm”.

AI2 stated that PV barriers are context specific; it depends on the location. For example if there is a renewable portfolio standard or a feed in tariff or any incentive program that a state offers, then PV would work well. However, in some jurisdictions where PV has not been encouraged with supporting policies, the process can be troublesome. In addition, finding interest among industry stakeholders poses a challenge. He further added that

“I have seen firsthand, where people do not understand PV; they do not understand how solar energy operates. They somehow think if there is a requirement for a building to support 25lbs of live loads and 30lbs of dead loads on a roof- if we put PV on it - for some reason we have to increase that. However, as long as the code does not require that, there should not be any added requirements. I consider that a knowledge and maybe an attitude issue”.

AI2 noted that, in his opinion, there is a minority of architects who are interested in PV; however, the majority of architects would not suggest it unless the client requests it. That is due to PV being out of architects' design vocabulary. He added that often a typical architect is going to resist incorporating PV within buildings because of all the additional design variables included; such as creating harmony between PV system and the rest of the building. The architectural profession requires architects, in some cases, to claim that they are interested in the environment to get a work assignment; but in the case of PV, their design knowledge might not be sufficient.

He asserted that it is very often that architects are being blinded by the design and not seeing other elements in the building that they should pay attention to. However, good architects are going to integrate them all and produce buildings that are beautiful and environmentally-responsive.

CI1 indicated that perhaps at this time, cost is probably considered one of the major barriers that slow down the PV adoption process. However, it should be emphasized that the cost of solar PV continues to decline at a rapid rate, so that over the next few years solar PV would be cost competitive to the electricity retail rate. Furthermore, the cost of BIPV, for example, from a product sample perspective, is still perceived as being expensive; however, if we look at the technology being integrated into the building envelope from a new construction standpoint (or an overall building cost standpoint) then the cost of BIPV would be relatively competitive. He explained that

“ ...it is more about the framing of the cost in relation to the overall building cost as opposed to the individual product cost (because BIPV includes a replacement of a building component and that could offset the cost), such kind of detail goes to the awareness and education of architects when it comes to integrating PV technology”.

Additionally, CI1 believes that barriers can be perceived differently from one jurisdiction to another. He stated that generally in jurisdiction where neither incentive programs are offered nor policies to promote PV are in action, PV barriers become more evident. Examples of barriers include the lack of experts and higher costs of installing PV systems, in addition to industry and end users' awareness. However in some regions where various policies are in place to promote renewable energy adoption, as in California where PV prices are currently competitive to retailed electricity, barriers are less noticeable.

CI2 commented that architects, developers and homeowners will tend to say that cost is a major issue. He stressed that it is very important to explain to clients that PV is not yet at grid parity (where the cost of the system over its life time is equal to the cost of displaced electricity) and that makes cost a barrier. Further, he added

“I remind people that buildings are not power stations where you need to generate electricity at the lowest cost, a building is an area where you live and serves many function and as such I think it allows the architect some freedom to integrate different building materials, try different approaches, not necessarily cost effective”.

CI2 further confirmed that the existence of an incentive program does accelerate the payback of the PV system. For example, in Ontario, Canada, the FIT has a huge impact. He believes that there are certainly things to be learnt and the application process could be simplified and improved. However, overall the FIT program has beneficial impacts towards an increase in PV users in the country. He stated that

“I was part of the PV program at the federal level at the Natural Resources Canada; we monitor the evolution of the price and the evolution of the installed capacity in Canada. At the moment we can say that 99% of the grid connected capacity is installed in Ontario, thanks to the FIT program”.

In addition, CI2 elaborated on the diffusion of PV technology in Canada by stating that it all depends on the market. In some markets that are off the North American electricity grid, PV has been cost effective since the 1990s. In such markets where PV is a commodity, it is considered the norm. For example, many electronic signs are powered by PV modules. This is considered the norm in the industry; PV modules in that context cost less money and require less maintenance than the alternative. However, in the case of grid connected applications, they are not at the same stage everywhere.

He explained that most Canadian provinces are still at the early adopter stage. However PV technology needs couple of more years until the price reaches grid parity, but once that price is reached, grid connected PV modules will become ubiquitous.

CI2 further explained that once grid parity is achieved, the big barrier to the dissemination of the PV technology will be how much the utility grid can accept the electricity generated from PV technology. Grid integration will then become the key challenge. He elaborated

“The challenge lays in how to prepare the utility grid to integrate more renewables, as such there are different mechanisms, different approaches, some experts tend to look at storage, but it is considered expensive. You can also look at load management, in other words how you can manage large loads. For example, water heaters can be turned on and off from the end users, so if there are large loads like this that can be used, more or less flatten these variations, I think that this is one of the solutions. This is where we are now in the research labs, is to look at what approaches can be used to overcome these penetration limits, to go from a maximum of 20-30% of penetration rate to be 60-70% of penetration rate”.

CI3 emphasized that in North America one of the primary challenges (with renewables in general) is not much of a cost but the perception that PV is an energy supplier versus a peak power supplier. He said that the discussion among stakeholders is focused on the high cost of producing electricity from solar panels and that is using average pricing or base pricing of

electricity in most jurisdictions in North America. However, he explains that the way solar produces electricity is in fact very close to the peak power period. Any type of peak power plant is paid substantially more than the average power prices.

He added that there are natural gas peak power plants in the Toronto area, ON that are paid CAD 20¢ /kWh versus the base price of CAD 6¢ /kWh. He stated that it is important to emphasize other benefits of solar PV such as power generation at the location of demand. The effective cost of delivered power is much lower than a power plant that is far away, in addition to the elimination of transmission losses. He asserted that it is essential to discuss the key benefits of solar PV so the issue of cost will not be misdirected.

CI3 also explained that in the case of BIPV, a building component is displaced in addition to the cost of PV systems' design and planning. Often architects consider what fits their design concepts rather than the cost of materials to create appealing building. Nevertheless, he claimed that if the cost of BIPV is compared to building materials (as per square feet basis); it is actually very competitive to the cost of high end cladding. He added

“...it is actually looking at the full cost of the building rather than the system itself, and looking at what architects are displacing, and then it becomes a very natural way to move forward using BIPV, providing the infrastructure to support that”.

Furthermore, CI3 commented on the Ontario FIT program by explaining that the timeline of new constructed projects (from project inception to the final completion stage) does not function well with the FIT application process. Newly constructed projects can take 3-4 years between initial design and occupancy, while the FIT application process takes approximately 18 months from start to end. Therefore, for clients who are considering BIPV applications, the timeline is a major barrier. He noted that, from his own experience, there are no barriers to the PV technology in

terms of building codes and standards perspective as long as buildings are designed to bear the extra dead loads of PV modules. However, the administrative process of obtaining the financial support/incentive is considered a barrier compared to other countries such as Germany, considered a leader in solar PV installations. For instance, in Germany, the FIT is a one page application form that has to be filled after the PV system installation is complete. Once the application is submitted, the customer gets automatically approved. Whereas in Ontario, the FIT application is a 40 page proposal that is submitted for approval according to a specific selection criteria.

CI3 concluded that it is very important not to consider the primary function of BIPV as an energy generator, but a building material. Architects' innovations are essential to apply this building product in various ways and make a statement out of it; to educate the general public about the multiple benefits of solar PV. It is a change of a mindset of what this technology is. In addition, He explained that BIPV has limited applications for homeowners, because usually PV is integrated into the roof of residential buildings, which is not very visible from human scale compared to curtain wall system or siding; therefore, the value of beauty and making a statement out of it is eliminated. However, in large commercial and institutional buildings, BIPV applications can be more visible and attractive.

4.4 Summary

In this Chapter, the findings from the web-based survey questionnaire and the in-depth interviews were presented.

The findings indicated that the majority of respondents are aware of PV technology benefits and are interested in deploying various PV products within their buildings; however, the findings also suggested that PV technology is not yet perceived to be mainstream in most jurisdictions due to barriers such as the high cost of PV systems, the lack of financial incentives (in some regions) and architects' practical knowledge.

It is noteworthy that respondents' answers to the majority of survey questions were highly consistent. This consistency indicates that the survey captured the range of experiences and opinions of the responding population and suggests that a higher response rate would not have provided deeper insight into this population. It would of course be valuable to access the non-responding population to understand their experiences and opinions, as well as their reasons for not responding.

Major findings will be discussed in detail in the following Chapter in order to answer the research questions presented in Section 1.3.

5 DISCUSSION

5.1 Introduction

During the last decade, photovoltaic technology applications within the built environment have been increasing due to many factors such as: a) Supportive policies and financial incentives from local/ provincial/state and federal governments -although the effectiveness of these policies varies widely. b) Technology advancement; and c) Increased awareness of PV benefits. This study investigated architects' level of awareness, interest and potential barriers responsible for lack of adoption of BIPV/BAPV in both Canada and the U.S.

Lists of architects were assembled from the RAIC and the AIA online directories. Architects were sampled regardless of their specialities and were requested to complete a survey questionnaire, followed up by an optional interview. Key informants were interviewed as well (refer to Chapter 3 for description of participant recruitment).

Survey results and interview findings were summarized in Chapter 4. The results indicated that the majority of respondents are aware of PV technology benefits and are very interested in deploying various BIPV/BAPV products within their buildings; however, the results also indicated that the technology is not yet perceived to be mainstream in most jurisdictions; due to factors such as the relatively high cost of PV systems, the lack of competitiveness with retail electricity prices, the absence of economic incentive policies (in some regions), and the complex and time-consuming administrative processes. Architects also lack practical knowledge of BIPV/BAPV system integration necessary during the buildings' design process, and perceived limits to PV grid capacity penetration are also seen as a constraint.

The purpose of this chapter is to reflect upon the survey results and interview findings presented in Chapter 4 in light of the research questions presented in Section 1.3:

1. To what extent are Canadian and American architects aware of BIPV/BAPV technology benefits?
2. To what extent are they willing to consider the deployment of BIPV/BAPV products within their projects?
3. What are the major barriers that might influence their decisions to adopt a BIPV/BAPV system?

This chapter is divided into three sections. The first section addresses architects' interest and awareness of BIPV/BAPV technology in both Canada and the U.S. The second section discusses the perceived barriers to adoption. The third section covers the implications of these results and proposes future areas for research.

5.2 Respondents' Awareness and Interest in BIPV/BAPV Technology

Research Question 1:

To what extent are Canadian and American architects aware of BIPV/BAPV technology benefits?

Identifying architects' level of awareness of and support for renewable energy technologies - in particular PV technology - is essential to achieving PV market penetration. Architects are an influential segment of the building industry, especially during the design phase. PV is often not included in the architectural design and is added after construction by an electrical engineer or a PV specialist. In such cases, PV panels, which are standardized and offer primarily an energy generation component, are often not in harmony with the rest of the building.

Architects can assist in transforming PV from an add-on energy generation element into a desired design feature that is either in harmony with the rest of the building or makes a visual statement by being distinctively contrasting in its color or appearance.

“Architects’ awareness” refers to having knowledge about PV technologies either through perception, experiences, education or professional training. It is evident from the survey results that the majority of respondents are aware of the technology benefits, and their awareness is mostly obtained from reading architectural magazines, networking with colleagues or on-line resources. However, most respondents also indicated that they did not have practical experience dealing with PV, because they have not been involved in a building design that included a PV component, or they did not have the sufficient practical knowledge to undertake one.

Results also show that some respondents’ awareness was a result of their knowledge/exposure to existing projects that applied or integrated PV. This kind of social comparison/pressure may assist knowledge transfer and therefore reduce some of the complexities associated with PV adoption. Social pressure is one of the main factors affecting respondents’ intentions to employ PV systems. Jager (2006) stated that people who perceive PV as a necessity to a sustainable future and have the adequate knowledge to overcome the complexities of the decision to purchase PV systems are more likely to make that decision.

According to the results presented in Chapter 4, the majority of Canadian and American respondents have never employed PV (Refer to Question 8, Figure 4.9). The reason behind that could be the lack of proper education about PV basics (See participants CA1, p.89, AI2, p.98) or might be linked to the fact that survey respondents believed that PV purchasing decision is a client’s decision (refer to Question 16, Figure 4.18). The decision may thus take a longer time

and considerable effort, in some jurisdictions where PV is not widely spread, due to the lack of satisfactory knowledge about economic returns, administrative procedure and/or the technical performance of PV systems. Proper education of clients, architects and industry specialists on the basic principles of passive and active solar designs, through academic resources or professional training, can assist in reducing some of the complexities associated with PV adoption decisions.

These findings align with previous studies (discussed briefly in Chapter 2, Section 2.8) and summarized here.

- The International Energy Agency SHC-Task 41, which focused on improving the qualifications of architects. \ The results of the survey that were administered under Task 41 revealed that there was a lack of knowledge regarding basic design principles for active and passive solar design(SHC-Task 41, 2012).
- A study conducted among young architects in Malaysia stated that 94% of respondents/architects were aware of BIPV technology and its benefits; whereas 77% of respondents had never integrated PV within their buildings (Mosik et al., 2013)
- Pasqualetti & Haag (2011) assessed the potential for solar PV in the American Southwest and investigated the essential skills that new graduates should have when joining the solar energy workforce. Their findings revealed that universities and workplaces need to introduce/increase solar training and education.

Research Question 2:

To what extent are they willing to consider the deployment of BIPV/BAPV products within their projects?

One of the significant factors in BIPV/BAPV technology adoption is the level of interest of stakeholders in the building industry. In this study, architects' interest in BIPV/BAPV applications was investigated. Survey results and interview findings indicate that lack of interest is not an issue; there is a big interest from the majority of respondents given that they have the opportunity to include PV systems within their buildings. In addition, respondents indicated that clients' support to the adoption decision is essential. However, client interest, which is outside of this study's scope, needs to be addressed independently, especially in the absence of financial incentives.

None of the surveyed or interviewed participants expressed a lack of interest. Architects' interest was greater in the case of new construction projects than retrofits, since BIPV systems should be included as early as the conceptual design phase. In the case of retrofit projects, architects feel constrained by the existing building envelope. Respondents also indicated that they are interested in integrating or applying different PV products, such as curtain wall systems, shading devices, and wall cladding, though greater interest from both American and Canadian respondents was in PV roofing products.

These results agree with the SHC-Task 41 findings which indicated that a lack of interest in PV among clients and developers was considered a major barrier ; whereas the lack of interest among architects was not (Farkas, Probst, & Horvat, 2012). The majority of architects who participated indicated that solar design principles are of great importance to their practice (Kanters, Horvat, & Dubois, 2014).

5.3 Barriers to BIPV/BAPV adoption

Research Question 3:

What are the major barriers that might influence their decisions to adopt a BIPV/BAPV system?

Various perceived barriers were identified by respondents and interview participants. The following sub-sections are categorized according to the survey and interview findings presented in Chapter 4.

5.3.1 Cost

According to the majority of respondents and interview participants (architects), cost is the most significant barrier perceived to slow down the adoption of PV technology in the building sector.

PV purchasing is considered one of the decisions that require high capital investment.

Respondents indicated that PV systems' long payback period, the high initial cost, and all the costs of permitting and insurance play major roles in their decision. Participants indicated that, from their own experience, it can be very hard to justify the additional first cost of PV systems, especially in the cases where financial government support is absent.

According to architects' experiences, the researcher concluded that lack of education among architects regarding PV economics is a major issue. Most often, architects are not included in the purchasing or permitting of PV systems. PV contractors, or electrical engineers in some cases, take over finances once the decision to employ PV is made. The specifics of how costs are distributed are not transferred to architects because such information is usually out of architects' vocabulary and responsibility. BIPV/BAPV cost in this study refers to the cost of the system as a whole including the balance of system (BOS) components. BOS refers to all components other than PV panels such as wires, racks, inverters and batteries (U.S. Department of Energy, 2006).

Education regarding PV cost-benefits, especially with the existence of government incentive programs, is essential to assist architects and clients in the decision-making process regarding PV adoption. For example, in addition to the environmental benefits gained from employing PV, such as the reduction in GHG emissions and air pollutants, PV can displace building materials (as in BIPV) and offset the displaced material cost towards PV systems' investment. Further, PV systems produce electricity that can be fed to the utility grid and purchased with/without the existence of financial incentive contracts. For example, if PV generated electricity is fed back to the grid under feed in tariffs (often a 20 year contract) that pay a favorable \$/kWh, the high upfront cost of PV can be compensated for and the monetary payback time would be shortened (the payback time differs depending on multiple variables such as the tariff paid, the size of the system, performance, location and other factors). However, with future R&D advancement to PV module cost and performance, environmental, energy and monetary payback times are also expected to improve (Fthenakis & Alsema, 2006; Raugei, Fullana-i-Palmer, & Fthenakis, 2012).

Key informants working in R&D (see AI1 p.98 and CI1 p.99) indicated that PV module cost is not a barrier, because PV module prices have decreased significantly. Candelise, Winskel, & Gross (2013) stated that multiple factors have caused the cost of PV panel production to fall significantly since the 1970s, such as improvements in the manufacturing processes, increased module conversion efficiency, and lower consumption of silicon. In addition, PV module prices have also been falling due to the growth of the global PV market, in particular, the vast production capacity of PV modules in China. For example, crystalline silicon (C-si) module prices have dropped by almost 45% between 2010 and 2012 (Candelise et al., 2013). Other costs associated with PV systems, called soft costs that include the installer/developer profit, system installation labor, sales tax, financing and customer acquisition, are highly variable by region

(Friedman et al., 2013). These costs also influence the BIPV/BAPV adoption decision. A study conducted by Zhang, Song, & Hamori (2011) found that PV installation costs have had a negative impact on the diffusion of PV in Japan.

PV cost trajectories predict that PV systems' prices will continue to decrease to a point where they reach grid parity, when the price of electricity generated from PV becomes competitive with the cost of electricity purchased from the utility grid. The time when PV reaches grid parity is highly variable due to differences in geographical location, technology improvements and financial subsidies (Reichelstein & Yorston, 2013).

5.3.2 Government Policies and Financial Support Mechanisms

PV is considered a capital-intensive investment and the existence of financial support mechanisms can relieve financial burdens from adopters and attract a higher volume of investment and adoption. Government policies that encourage renewable energy generation by establishing targets are essential to push innovative clean technologies forward.

The results described in Chapter 4 indicate that the existence of government support policies, such as the Ontario Green Energy Act, and financial incentives, such as Ontario feed in tariffs and Hydro Quebec grants can assist in promoting PV technology within the building sector. Interview participants and survey respondents indicated that the absence of such mechanisms is considered a major barrier. Most respondents indicated that they are not aware of any financial support mechanisms due either to the absence of support programs in their regions or due to their lack of awareness of such programs. However, key informants asserted that policy intervention is required to push the technology forward-in some jurisdictions because PV adoption varies

widely by state/province (see AI1, p.98). Interview participants indicated that one of the major drivers in their clients' decisions in adopting PV systems, beside their environmental awareness, is the existence of government financial support (see CA3, p.96).

However, the existence of support policies does not always guarantee high volumes of investment unless these policies are effective. To explore whether government policies such as feed in tariffs have any impact on respondents' awareness and PV deployment, responses from Ontario were compared against the rest of Canadian architects' responses. The results in Table 5.1 indicate that a higher proportion of Ontario architects responded that they are aware of both PV technology and financial support mechanisms than architects from the rest of Canada.

Approximately similar proportions of architects from Ontario and the rest of Canada reported having employed BIPV/BAPV systems, and a higher proportion of architects from the rest of Canada reported having interest in employing BIPV/BAPV in the future. Higher awareness of PV technology and financial support among Ontario architects could be inferred to be a result of the FIT in place there. The perception that FIT paperwork is troublesome may be responsible for depressing the interest in employing PV in future projects among Ontario architects and reducing the number of projects employing PV below what would be expected under the generous FIT policy.

Table 5.1: Comparison between Ontario's respondents and the rest of Canadian respondents.

	Ontario's responses (n=27)	Rest of Canada's responses (n=35)
Awareness of BIPV/BAPV technology	25	22
Employed either BIPV/BAPV systems	7	10
Aware of government incentives	4	2
Interested in employing BIPV/BAPV both new construction and retrofit	18	30

In addition, interview participants indicated that the administrative procedures are troublesome in some jurisdictions and hold back adopters from purchasing the system (see CI3 p.103).

Simplicity, short time for approval, and affordability of permits are all essential to attract more investment (see Section 5.3.3).

In this study, respondents identified various financial support programs³ that encourage PV adoption (See Q 14, Table 4.4). The results presented above align with studies finding that economic support policies initiated by governments have positive impacts on the decision of adopting PV systems (Martin & Rice, 2013; Mabee, Mannion, & Carpenter, 2012; Verbruggen & Lauber, 2012; Zhang et al., 2011). Setting up simple and effective financial support mechanisms can affect manufacturing capacity and provide employment opportunities, increasing the rate of BIPV/BAPV adoption.

PV LEGAL, a project that was supported by Intelligent Energy Europe, aimed to identify administrative barriers and offer solutions to decrease the bureaucratic barriers that may restrain PV diffusion in Europe (Garbe et al., 2012). This study's findings also align with PV LEGAL findings regarding administrative barriers. This study's respondents pointed out that the application procedure for PV financial support requires a great deal of paper work, can be expensive, and requires long waiting periods for review.

5.3.3 Grid-Connection Administrative Process

Connecting PV systems to utility grids is perceived as a roadblock by some interviewed and surveyed respondents (even though it is the final step in PV system installation). The connection

³ State/provincial/federal incentive programs

process involves many guidelines and technical qualifications defined by utility operators.

Participants reported that the application process to obtain a permit to connect to the utility grid was relatively long and required multiple hours and steps to complete. In addition, it could take a long time for applications to be reviewed and approved before a PV system begins feeding electricity to the grid and earning income. There is no guarantee beforehand that the purchased system will be connected to the grid. However, participants referred to PV systems that are over 10kW and connected as part of the Ontario FIT program. For Micro FIT (<10kW) and small residential generators the connection process is simpler with a lead time of 1-6 months and no other required approval (Ontario Power Authority, 2013). There is no requirement to undergo a Transmission Availability Test (TAT) to determine if there is available capacity on the grid, a test that is required for larger systems (>10kW) that are installed under FIT (Yatchew & Baziliauskas, 2011).

Adachi (2009) interviewed customers in order to learn about their experiences connecting to the grid in Ontario. He reported that 10 consumers had a positive experience, 7 reported a negative experience and 7 reported mixed experiences with their local distribution companies. It is difficult to conclude that the process was a uniform roadblock. The process to connect to the grid has been recently streamlined and fully explained with the duration of the connection process estimated to be 18 months to 3 years for systems $\leq 10\text{kW}$ (Ontario Power Authority, 2013).

Tweedie & Doris, (2011) compared the interconnection processes for PV systems in Germany and California, both leaders in streamlining and simplifying the grid connection process. Results showed that administrative procedures were similar in both jurisdictions in terms of application paperwork burden and requirements for small scale generators. Small residential PV systems

required less paper work (≈ 8 pages) and shorter review and approval (less than 1 month) compared to large scale generation.

Key informants (working in R&D) indicated that there are future concerns regarding grid capacity involving infrastructure constraints that may restrict PV systems from connecting to the utility grid. This happens when high volumes of PV systems are installed and their output is more than the local grid can handle. This issue is often linked to inadequate utility planning. The grid capacity issue needs further research and development to manage the amount of generation and enhance the grid's capacity. Some of the solutions discussed by key informants and the literature are either introducing energy storage or shifting the operating times of processes that require substantial amounts of energy (Sonvilla, Zane, Poblocka, Brückmann, & Vandenberg, 2013; Bosetti, Catenacci, Fiorese, & Verdolini, 2012; European Photovoltaic Industry Association, 2011a). In most jurisdictions in Canada and the United States, the grid capacity issue is not currently perceived as a barrier because renewables represent a small percentage of generation (less than 1% of the total generation capacity in Canada) (Luukkonen et al., 2012).

This study's results align with PV GRID. A PV GRID initial report issued in April, 2013 indicated key barriers that were identified through qualitative measures. Among the most significant were the permitting procedures that include "PV installation permit and electricity production licences, grid-related barriers such as grid access, capacity limits, operation and maintenance, and the technical requirements of PV systems" (Sonvilla et al., 2013, p.6).

5.3.4 Education

According to the interview findings, lack of education among architects regarding the basic principles of solar design is considered one of the barriers to PV implementation. This may be due to architects' academic curriculum in North America does not contain sufficient practical information regarding the proper application of solar design strategies. Another important factor is that architects, due to their training, design buildings with surfaces in mind. They pay attention to areas, angles, colors, textures, appearance and transparency of building materials. PV systems are designed and measured by their efficiency and performance; they are not treated with the same vocabulary that architects are familiar with (see participants CA1, p.90, AI2, p.98). Therefore, the development of architecturally appealing PV products is important.

Clients' knowledge and acceptance of PV technology plays a major role in architects' designs. The majority of survey respondents indicated that even though clients and designers work together to achieve the end results; it is still the clients' decision when it comes down to economics (see Figure 4.18). Future work should clearly add clients' interest and knowledge to the architects' perspective studied here.

5.4 Implications and Future Area for Research

This study intended to shed light on architects' awareness, interest and perception of potential barriers that might influence the decision to adopt BIPV/BAPV systems in Canada and the U.S. Results suggest that architects are aware of the technology benefits and are very interested in employing PV products in different applications within their building designs. However, results also revealed that architects' level of awareness does not include, in most cases, practical

knowledge of PV applications and economics. Therefore, they could be insufficiently prepared to present PV options to their clients.

Furthermore, this study's findings revealed that there are multiple barriers responsible for slowing down the PV adoption process in various jurisdictions in Canada and the United States. These barriers include the capital cost of PV systems, the absence of government financial support mechanisms, the difficulties in administrative procedure regarding PV system installation, the process of grid connection, and the lack of knowledge and education among industry stakeholders and clients.

It is important to point out that this study was designed to identify and understand barriers. This is only one side of the equation, as identifying barriers is the first step in finding strategies to eliminate them. Despite the low response rate obtained in this study, architects' responses were highly consistent, and this low variability, as well as their consistency with previous studies, lends confidence to the results (refer to respondents' profile in Section 4.2.3)

This research investigated architects' perspectives, though other stakeholders (such as clients) are also important. Additional research is needed to address client interest and awareness of BIPV/BAPV benefits. Another area of potential research is the architectural appearance of PV products. It would be beneficial and interesting to see how PV products can be integrated into the building envelope and how architects would incorporate PV products as they usually handle traditional building materials. Development of a directory of available PV options in a language that is in harmony with the architectural design vocabulary would be an asset. Another area of future research lies in identifying proper communication and education tools to facilitate PV education and awareness among architects and clients. It would be of value to determine which communication tools are most successful in reaching the different audiences involved in PV

adoption. Other areas of future research could identify the gaps in the architectural curriculum in Canada and the United States. It would be valuable to know if environmentally-responsive design strategies and PV technology advancement are universally included in the architectural curriculum.

5.5 Recommendations

The removal of barriers identified above requires collaboration from stakeholders at the federal, state/provincial and local level. BIPV/BAPV adoption requires stable government support and policy intervention in order to become ubiquitous. Following from the results in Chapter 4, some of the recommendations are:

- Establish policies to promote the adoption of renewable energy sources.

As discussed earlier, the Ontario Green Energy Act, California's RPS, and the German experience all indicate that political support and government policies are key instruments in promoting renewables on a provincial/state and national level. In addition, Table 5.1 (Section 5.3.2) shows that there is a positive relationship between the existence of supporting policies (such as Ontario's FIT) and respondents' awareness and experience in employing PV. For example CA3 stated that the motivation behind employing BAPV systems was primarily economic. His client found that PV was feasible considering the opportunity of making it part of the FIT program. CA1 added that cost was the major barrier to installation and this barrier was lessened when the project received a financial incentive from Hydro Quebec.

In addition, establishing renewable energy targets (RET) can assist in the expansion of renewables and PV in particular. In some jurisdictions a combination of support mechanisms

(such as major policies of feed in tariffs, and supplementary ones such as tax relief or rebates) might be needed to meet established targets (Kitzing, Mitchell, & Morthorst, 2012).

- Provide financial support mechanisms to promote BIPV/BAPV adoption. According to the survey and interview findings, PV cost is perceived as the most substantial barrier slowing down PV adoption. Therefore, providing financial support mechanism to small and large scale PV systems' adopters could promote further deployment. In addition, ensuring transparency in disclosing PV systems' associated costs to clients would set up their expectations regarding PV capital cost and its financial return early on in the process.

- Ensure further investments in marketing and education tools to promote PV products and explain PV benefits and applications to a larger audience of architects.

This study describes the need of governments and architectural bodies to work together to educate architects about PV benefits and applicability within newly constructed and retrofitted buildings. This could be achieved through multiple marketing tools, offering affordable training sessions to architects and demonstrating good examples of projects that have employed BIPV/BAPV products through publications and open house visits. Further, enhancing the architectural curriculum to include sufficient theoretical and practical knowledge about basic passive and active design principles and PV products and applications would strengthen architects' knowledge.

5.6 Conclusion

Reducing the dependency on fossil fuel through the adoption of PV is a component in mitigating the adverse effects of climate change. Integrating or applying PV in buildings benefits from the collaboration of architects in the building design phase. Recognizing the importance of architectural incorporation of PV; this study aimed to shed light on architects' awareness and interest in employing PV. In addition, it aimed to identify the major perceived barriers responsible for slowing down the BIPV/BAPV adoption process.

The significance of this study lies in providing information to federal/provincial/state and local governments (see examples of government programs in Table 4.4), policy makers and educators about architectural integration of PV. The results show that architects are aware of PV and there is interest in BIPV/BAPV products (see Figure 4.6); however, there are a number of barriers (that vary largely from one jurisdiction to another) identified that need to be eliminated in order to push the adoption of PV forward. Cost is currently perceived by architects as the major roadblock to the diffusion of PV technology by survey and interview participants (See Figure 4.16 , Figure 4.17 and Section 4.3.2.2) though this perception is not shared by interviewed key informants.

Once PV becomes cost competitive with other traditional energy sources; PV adoption is expected to grow within the building industry. Raising awareness, proper PV training and education, streamlining the administrative processes of financial support mechanisms and grid integration would accelerate PV adoption.

Appendix A

Study's Background and Objectives

▪ Web-Questionnaire Information letter

Title of Project: Building Integrated and Applied Photovoltaic: Barriers to Adoption.

You are invited to participate in a research study conducted by Ola Mousa, under the supervision of Dr. Geoffrey Lewis from the School of Planning of the University of Waterloo, Canada. Please be advised that your contact information has been obtained of a publicly accessible architects' directory in both Canada and the U.S.

The purpose of this study is to explore the deployment of Building Integrated and Applied Photovoltaic products within the construction sector in Canada and the U.S. It also investigates the potential drivers and barriers that might influence the decision of construction sector's professionals (architects, planners and developers) about implementing a BIPV/BAPV system within their schemes. The study is for a Master's thesis.

If you decide to volunteer, you will be asked to complete a 10-minute online survey*. It is difficult to conduct an anonymous questionnaire due to the need to follow up with participants after the survey is completed. However, the researcher guarantees the confidentiality of participants by limiting access to the identified data by assigning security codes to the survey data and properly disposing them once the study is complete in one year from the date of this letter. Survey questions focus on measuring architect's interest, awareness and the potential barriers that may be restricting the deployment of the Building Integrated Photovoltaic technology. Participation in this study is voluntary. You may decline to answer any questions that you do not wish to answer and you can withdraw your participation at any time by not submitting your responses. There are no known or anticipated risks from participating in this study.

It is important for you to know that any information that you provide will be confidential. All of the data will be summarized and no individual could be identified from these summarized results. Furthermore, the online survey is programmed to collect responses alone and will not collect any information that could potentially identify you (such as machine identifiers).except for the participants who identified that they have undergone a BIPV/BAPV project and have provided their email addresses and have indicated their interest to be interviewed.

If you wish to participate, please visit the Study at the web link provided in the email invitation. The data, collected from this study will be maintained on a password-protected external hard drive in a restricted access area of the university. As well, the data will be electronically archived after completion of the study and maintained for one year and then erased. Should you have any questions about the study, please contact either Ola Mousa, T: 5192084151 email: o2mousa@uwaterloo.ca or Geoffrey Lewis, email:g4lewis@uwaterloo.ca. Further, if you would like to receive a copy of the results of this study, please contact either investigator. I would like to assure you that this study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, please feel free to contact Dr. Maureen Nummelin in the Office of Research Ethics at 1-519-888-4567, Ext. 36005 or maureen.nummelin@uwaterloo.ca.

Thank you for considering participation in this study.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

☐ "I agree to participate."

☐ "I do not wish to participate (please close your web browser now)."

**This survey uses Survey MonkeyTM which is a United States of America company. Consequently, USA authorities under provisions of the Patriot Act may access this survey data. If you prefer not to submit your data through Survey MonkeyTM, please contact one of the researchers so you can participate using an alternative method (such as through an email or paper-based questionnaire).*

▪ **Web-based Survey Questions**

Respondents' Background	Q1	Consent to participate	I agree		I do not agree	
	Q2	Country	Canada		United States	
	Q3	Province/State				
	Q4	Select your Specialty	Commercial, Residential, Institutional, Other.....			
Research Question #1	Q5	Are you aware of Building Integrated/Applied Photovoltaic (BIPV/BAPV) Technology?	Yes		No	
	Q6	If your answer was Yes above, how did you hear about it?	TV, Radio, online, magazine, friend, brochures, Colleagues, other.....			
	Q7	Are you aware of any buildings (beside your project) that either Applied (Roof-Mounted) or Integrated Photovoltaic	Yes		No	
	Q8	Have you either employed Applied Photovoltaic (BAPV-Roof-Mounted), or Integrated Photovoltaic (BIPV) in any of your projects?	Yes		No	
	Q9	If you have employed BAPV, what building component?	Roof Mounted, Siding, Awnings Other.....			
	Q10	If you have employed BIPV, what building component?	Roof Integrated, Skylight, Curtain wall, Siding, awnings, Other.....			
Research Question #2	Q11	If you employed either BAPV or BIPV in any of your projects, would you be interested in participating in an interview to further discuss it?	Yes		No	
			If Yes, Please provide your email address.....			
	Q12	If you answered NO, would you be Interested in including a BIPV system in your designs in the future?	Yes New Retrofits	Maybe New Retrofits	No	
Research Question #3	Q13	Which building component would you most likely replace with BIPV?	Roof, Window, Skylight, Curtain wall, Siding. Other			
	Q14	Are you aware of any government incentives or any other programs that encourage the deployment of BIPV/BAPV?	Yes		No	
			Which program.....			
	Q15	Rank BIPV/BAPV potential barriers according to their significance?	Cost, Codes and Permits, Financial Incentives, Availability of products, Installation experience, Policy and Regulations, Grid Connection process, Others.....			
	Q16	Do you think adopting BIPV/BAPV is clients Or designers decision?	Clients		Designers	

▪ Interview Verbal Consent

The initial contact with the interviewee has been established via email, and a convenient time for both the interviewer and the interviewee has been agreed upon.

Introductory statement:

Hello, my name is Ola Mousa. I am a graduate student pursuing my masters of environmental studies in Planning from the University of Waterloo.

I would like to thank you for agreeing to participate in this interview.

I am collecting information about the potential barriers that may affect the decision to adopt a Building Integrated Photovoltaic system. The main reason behind conducting this research is measuring the construction industry awareness level and interest as well as the potential barriers that the industry might face in acquiring a system.

This interview will take approximately 20-30 minutes. You are not obligated to answer any question if you do not wish to do so. You are free to ask for any questions or clarifications at any time. You may withdraw your consent at any time without penalty by advising me (the researcher). You have the option of allowing the interview to be audio/video recorded to ensure an accurate recording of my responses.

Please be aware that excerpts from the interview may be included in the thesis and/or publications to come from this research, with the understanding that the quotations will be anonymous.

With full knowledge of all foregoing, do you agree, of your own free will, to participate in this study?

Do you agree to have my interview audio or video recorded?

Do you agree to the use of anonymous quotations in any thesis or publication that comes of this research?

Thank you for your consent.

▪ **Sample of Interview Questions**

Q1: How did the idea of integrating PV initiated? Who brought it up? What was the motive behind it or the driver that initiated it (such as LEED certification, the appearance of being a green project, client decision, and financial savings)?

Q2: Were everybody on board? Or some objections were raised?

Q3: What was different about the design process? Any extra expertise needed?

Q4: Describe the road blocks or the barriers that the project faced? And how did you overcome them?

Q5: What were the factors that led to the decision to favor BIPV over BAPV?

Q6: How did the financial benefit of integrating PV played a role in your decision?

Q7: Describe the process of connecting to the utility grid? Would you say it was an easy or a difficult process?

Q8: In terms of project construction, were the products standard or customized?

Q10: Did you have any difficulty finding installers or did you have to train a staff yourself?

Q11: What aspects of the BIPV system are you happy with? What aspects are you dissatisfied with?

Q12: In your opinion, what are the lessons learned from this project? What would you do differently to make the process easier?

Appendix B

Table B- 1: Distribution of Sent and Received Questionnaires from Various Canadian Provinces.

Province/Territory	Symbol	No. of RAIC Architects	Number of Sent Surveys	Number of Responses Received	Invalid Responses	Response Percentage per Province
Alberta	AB	436	46	10		17%
British Columbia	BC	590	92	13		22%
Manitoba	MB	182	19	1		2%
New Brunswick	NB	45	7	0		0%
Newfoundland and Labrador	NL	26	0	0		0%
Northwest Territories	NT	10	4	1		2%
Nova Scotia	NS	102	13	1		2%
Nunavut	NU	2	0	0		0%
Ontario	ON	1627	160	27		47%
Prince Edward Island	PE	10	1	0		0%
Quebec	QC	340	42	4		7%
Saskatchewan	SK	84	6	1		1%
Yukon	YT	6	0	0		0%
Total		3460	392	58	4	100%
<i>Non-response</i>	291					
<i>Opted out</i>	25					
<i>Bounced</i>	12					

Table B- 2: Distribution of Sent and Received Questionnaires from Various U.S. Regions/Sub-regions

United States Regions*	No. of Sent Surveys	No. of Responses Received	Invalid Responses	Percentage (%)**
Region I: Northeast				
New England (<i>CT, ME, MA, VT, NH, RI</i>)	57	4		11
Middle Atlantic (<i>NJ, NY, PA</i>)	67	5		14
Region I Total	124	9		25
Region 2: Midwest				
East North Central (<i>IN, IL, MI, OH, WI</i>)	78	4		11
West North Central (<i>ND, SD, NE, KS, MN, MO, IA</i>)	46	3		8
Region 2 Total	124	7		19
Region 3: South				
South Atlantic (<i>DE, DC, MD, WV, VA, NC, SC, GA, FL</i>)	126	6		16
East South Central (<i>KY, TN, AL, MS</i>)	33	1		3
West South Central (<i>AR, OK, TX, LA</i>)	59	0		0
Region 3 Total	218	7		19
Region 4: West				
Mountain (<i>MT, WY, ID, NV, UT, CO, AZ, NM</i>)	75	9		24
Pacific (<i>WA, OR, CA, AL, HI</i>)	89	5		13
Region 4 Total	164	13		37
Total	630	37	3	100
<i>Non-response</i>	556			
<i>Opted out</i>	29			
<i>Bounced</i>	5			

*According to (U.S. Department of Commerce Economics & U.S. Census Bureau, 2010)

** Percentages are rounded

Table B- 3: Respondents' Valid/Invalid Consents

With full knowledge of all foregoing ,I agree ,of my own free will, to participate in this		
	Canada	United States
	Frequency/ Percentage	Frequency/ Percentage
<i>"I agree to participate".</i>	58 (94%)	37 (93%)
<i>"I do not wish to participate".</i>	4 (6%)	3 (7%)
Total	62 (100%)	40 (100%)

Table B- 4: Canadian and American respondent's Architectural Specialties

Respondents' Architectural Specialties			
Country		Canada	United States
Valid Responses	Specialty*	Frequency/ (Percentage)**	Frequency/ (Percentage)**
	Commercial	24 (46%)	18 (56%)
	Institutional	39 (75%)	16 (50%)
	Single-family Residential	14 (27%)	14 (44%)
	Multi-family Residential	15 (29%)	7 (22%)
Invalid/Skipped		10	8
Total Reponses		52	32

* Respondents have selected one or multiple specialties

** Percentages are rounded.

Table B- 5: Canadian Respondent's Awareness of BIPV/BAPV Technology

Canadian Respondents			
		Canada	Unites States
Valid Responses	Response	Frequency/ (Percentage)*	Frequency/ (Percentage)*
	Yes	47 (87%)	32 (89%)
	No	7 (13%)	4 (11%)
Invalid/Skipped		8	4
Total		54 (100%)	36 (100%)

* Percentages are rounded.

Table B- 6: Respondents’ methods of BIPV/BAPV Awareness

Communication Mode		Canada Frequency/	United States Frequency/
Valid	TV	1 (3%)	0 (0%)
	Radio	1 (3%)	0 (0%)
	Online	15 (38%)	12 (46%)
	Magazines	24 (60%)	14 (54%)
	Brochures	9 (23)	2 (8%)
	Colleagues	18 (45%)	10 (38%)
Invalid/skipped		22	14

* Respondents have selected one or multiple modes of communication

Table B- 7: Respondents’ Awareness of Projects Other Than Their Own That Have BIPV/BAPV

Valid Responses	Canada	United States
Aware of Projects that have either BIPV or BAPV	37 (67%)*	23 (64%)
Not Aware of any Projects.	18 (33%)	13 (36%)
Invalid/Skipped answers	7	4
Total of valid answers	55 (100%)	36 (100%)

* Percentages are rounded

Table B- 8: Respondents Answers to: “Have you either employed Applied Photovoltaic (BAPV-Roof-Mounted), or Integrated Photovoltaic (BIPV) in any of your projects?”

Valid Responses	Canada	United States
Have employed BIPV or BAPV	17 (31%)*	13 (43%)
Have employed neither BIPV nor BAPV	38 (69%)	17 (57%)
Invalid/Skipped	7	10
Total	55	30

* Percentages are rounded.

Table B- 9: Respondents’ Answers to Q9: “If you have employed BAPV, what building component?”

Components	Canadian Valid Responses/ percentage**	American Valid Responses/ percentage**
Roof-Mounted	15 (94%)	10 (83%)
Siding	2 (13%)	2 (17%)
Awning	4 (25%)	2 (17%)
Invalid/Skipped responses	36	28

*Some respondents have applied one or more of the listed components

**Percentages are rounded.

Table B- 10: Respondents’ Answers to Q10: “If you have employed BIPV, what building component?”

	Canada Valid Responses*/ Percentage	United States Valid Responses*/ Percentage
Roof-integrated	6 (50%)	7 (88%)
Curtain wall system	3 (25%)	0 (0%)
Skylight	4 (33%)	0 (0%)
Awning	3 (25%)	1 (12%)
Siding	2 (17%)	1 (12%)
Invalid/Skipped Responses	50	32

*Some respondents have applied one or more of the listed components.

**Percentages are rounded.

Table B- 11: Canadian and American Respondents’ answers to Question 11: “if you employed either BAPV or BIPV in any of your projects, would you be interested in participating in an interview to further discuss it?”

Respondents	Valid Responses	Invalid/Skipped	Percentage (%)
Canadian Respondents	Yes (9)	31	29
	No (22)		71
American Respondents	Yes (3)	20	15
	No (17)		85

Table B- 12: Respondents’ Interest in Including BIPV/BAPV Systems in their Future Designs

	Canadian Respondents (n=45)	American Respondents(n=29)
Yes, new	29 (64%)*	20 (69%)
Yes, retrofit	19 (42%)	15 (52%)
No	0 (0%)	0 (0%)
Maybe	17(38%)	8 (28%)
Invalid/Skipped	17	11

*Respondents provided one or multiple choices for this question

Table B- 13: Canadian and American Respondents’ Answers to Question 13: “Which building component would you most likely replace with BIPV?”

Building Component	Canada-Valid Answers* /Percentage	USA-Valid Answers* /Percentage
Roofs	37 (90%) **	23 (82%)
Windows	13 (32%)	6 (21%)
Skylights	22 (54%)	10 (36%)
Curtain wall system	20 (49%)	12 (43%)
Siding	15 (37%)	12 (43%)
Awnings	17 (14%)	14 (50%)
Invalid/Skipped	21	12

*Some respondents chose one or multiple components.

**Percentages are rounded.

Table B- 14: Canadian and American Respondents’ Answers to Question 14“Are you aware of any government incentives or any other programs that encourage the deployment of BIPV/BAPV?”

	Valid Responses/ Percentage* (Canada)	Valid Responses/ Percentage (United States)
Yes, I am aware.	6 (11%)	12 (40%)
No, I am not.	49 (89%)	18 (60%)
Invalid/Skipped	7	10

*Percentages are rounded.

Table B- 15: Canadian Respondents’ Answers to Question 15: “Rank BIPV/BAPV potential barriers according to their significance?”

Potential Barrier	Number of Canadian Respondents/ (Percentage %)*								Total	Average Ranking
<i>Barriers Ranking 1-8</i>	<i>1st</i>	<i>2nd</i>	<i>3rd</i>	<i>4th</i>	<i>5th</i>	<i>6th</i>	<i>7th</i>	<i>8th</i>		
Cost	30 59%	6 12%	2 4%	3 6%	4 8%	0 0%	2 4%	4 8%	51	6.53 (1 st)
Codes and Permits	2 4%	6 12%	11 22%	4 8%	7 14%	12 24%	6 12%	3 6%	51	4.37 (5 th)
Financial Incentives	6 12%	19 37%	6 12%	8 16%	7 14%	3 6%	2 4%	0 0%	51	5.84 (2 nd)
Availability of Products	4 8%	10 20%	10 20%	13 25%	7 14%	4 8%	3 6%	0 0%	51	5.35 (3 rd)
Installation Experience	0 0%	5 10%	8 16%	11 22%	10 20%	12 24%	3 6%	2 4%	51	4.35 (6 th)
Policy and Regulation	3 6%	1 2%	2 4%	2 4%	1 2%	8 16%	20 39%	14 27%	51	2.65 (7 th)
Grid Connection Process	4 8%	4 8%	10 20%	10 20%	13 25%	4 8%	5 10%	1 2%	51	4.80 (4 th)
Others	2 4%	0 0%	2 4%	0 0%	2 4%	8 16%	10 20%	27 53%	51	2.10
Invalid/Skipped responses									11	

*Percentages are rounded.

Table B- 16: American Respondents’ Answers to Question 15: “Rank BIPV/BAPV potential barriers according to their significance?”

Potential Barrier	Number of American Respondents/ (Percentage %)*								Total	Average Ranking
<i>Barriers Ranking</i> 1 st to 8 th	1 st	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th		
Cost	15 58	4 15	3 12	1 4%	0 0%	1 4%	0 0%	2 8%	26	6.77 (1 st)
Codes and Permits	4 15	5 19	6 23	3 12	5 19	2 8%	1 4%	0 0%	26	5.62 (3 rd)
Financial Incentives	1 4%	6 23	3 12	6 23	4 15	2 8%	3 12	1 4%	26	4.88 (4 th)
Availability of Products	4 15	6 23	4 15	4 15	5 19	3 12	0 0%	0 0%	26	5.65 (2 nd)
Installation Experience	1 4%	1 4%	3 12	4 15	1 4%	9 35	7 27	0 0%	26	3.77 (6 th)
Policy and Regulation	0 0%	1 4%	4 15	3 12	0 0%	4 15	4 15	10 38	26	2.92 (7 th)
Grid Connection Process	1 4%	2 8%	2 8%	4 15	9 35	4 15	3 12	1 4%	26	4.19 (5 th)
Others	0 0%	1 4%	1 4%	1 4%	2 8%	1 4%	8 31	12 46	26	2.19
Invalid/Skipped responses									14	

*Percentages are rounded.

Table B- 17: Respondents Answers to Question 16 “Do you think adopting BIPV is clients’ or designers’ decision?”

Power of decision making	Canada Responses*/Percentage**	United States Responses/Percentage
Clients	43 (93%)	20 (91%)
Designers	20 (43%)	7 (32%)
Invalid/Skipped Responses	16	18

* Respondents selected one or both options

** Percentages are rounded

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